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VORONEZH STATE UNIVERSITY
NOVOVORONEZH NUCLEAR POWER PLANT

LXVIII INTERNATIONAL CONFERENCE

«NUCLEUS 2018»

FUNDAMENTAL PROBLEMS OF NUCLEAR PHYSICS, ATOMIC POWER ENGINEERING AND NUCLEAR TECHNOLOGIES

DEDICATED TO THE CENTENNIAL OF VORONEZH STATE UNIVERSITY AND TO THE 80th ANNIVERSARY OF THE BIRTH OF K. A. GRIDNEV

BOOK OF ABSTRACTS
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LXVIII INTERNATIONAL CONFERENCE «NUCLEUS 2018». FUNDAMENTAL PROBLEMS OF NUCLEAR PHYSICS, ATOMIC POWER ENGINEERING AND NUCLEAR TECHNOLOGIES (LXVIII MEETING ON NUCLEAR SPECTROSCOPY AND NUCLEAR STRUCTURE).
BOOK OF ABSTRACS.
Editor A.K. Vlasnikov

The scientific program of the conference covers almost all problems in nuclear physics and its applications such as: neutron-rich nuclei, nuclei far from stability valley, giant resonances, many-phonon and many-quasiparticle states in nuclei, high-spin and super-deformed states in nuclei, synthesis of super-heavy elements, reactions with radioactive nuclear beams, heavy ions, nucleons and elementary particles, fusion and fission of nuclei, many-body problem in nuclear physics, microscopic description of collective and single-particle states in nuclei, non-linear nuclear dynamics, meson and quark degrees of freedom in nuclei, mesoatoms, hypernuclei and other nuclear exotic systems, double beta-decay and neutrino mass problem, interaction of nucleus with electrons of atomic shell, verification of theories of elementary particles interaction and conservation laws, physics of nucleus and particles in application to astrophysical objects, theory of direct and statistical nuclear reactions, theory of multiple scattering, theory of reactions with clusters and heavy ions, theory of relativistic nuclear collisions, theory of polarization phenomenon in nuclear reactions, theories of proton, two-protons and cluster radioactivity and fission of nuclei, instruments and methods of nuclear-physical experiment, analysis of measurements, accelerators, radio-ecology, application of nuclear-physical experimental methods to astrophysics, medicine and other fields of research, fundamental problems of nuclear power and nuclear technologies, experience and problems of qualitative training of Russian and foreign specialists in field of nuclear physics, atomic power engineering and nuclear technologies.

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The history of Voronezh State University is closely connected with the University of Tartu (Yuryev) opened in 1802 by the decree of Emperor Alexander I, and in 1918, in accordance with the decision of the Large State Commission "transported" to the city of Voronezh. The events of the First World War and the Great Patriotic War - evacuation, destruction of educational buildings, looting of books - tested the viability of the university, which managed to preserve and increase scientific and educational potential in the situation of acute shocks.

Throughout its history, the VSU has been dynamically developing: new specialties and areas of training have been opening, successfully combining the traditions of classical fundamental education and modern technologies that take into account the global changes taking place in our country. Today, our university continues to hold the leading positions in the sphere of Russian education; its graduates are highly qualified and competitive personnel for various spheres of the country's life.

The university has always been proud of its graduates. They have been working in large companies and universities in many countries around the world. They are talented scientists, laureates of State prizes, Heroes of Labor, academicians, ministers, scientists and cultural figures, famous lawyers, leading IT specialists. Among the Nobel laureates is the Russian physicist and outstanding graduate of VSU Pavel Alekseevich Cherenkov. In 1958, he was awarded a high prize for the discovery and explanation of the specific blue glow.

VSU is considered to be the innovative leader of the region. No university department stands aside; they all conduct active research work in their fields. Scientists of the university represent new innovative projects and developments, working both on the basis of the university and together with large enterprises of Central Black Soil region. Voronezh State University takes an active part in innovative development of the city and region, cooperating with various business structures, implementing joint innovative projects.

In September 2018, Voronezh State University celebrates its 100th anniversary. This date is of great importance not only for the city itself, but is also considered as a federal level event. For Voronezh, the university's centennial promises to become a grandiose holiday. In 2017, an organizational committee was formed to prepare for the 100th anniversary, which was headed by Plenipotentiary Representative of the President of the Russian Federation in the Central Federal District (formerly Governor of Voronezh Region) Alexei Gordeyev. The Minister of Education and Science of the Russian Federation, Olga Vasilieva, co-chaired the meeting. The jubilee program is being implemented in all directions of VSU activities, which involve graduates, students, school leavers, and Russian and foreign partners of the university. The key event will be a solemn celebration of the 100th anniversary on September 15, 2018, which will be combined with the celebration of the Day of the City of Voronezh.

THE 80th ANNIVERSARY OF THE BIRTH OF PROFESSOR K. A. GRIDNEV (08.02.1938—10.06.2015)

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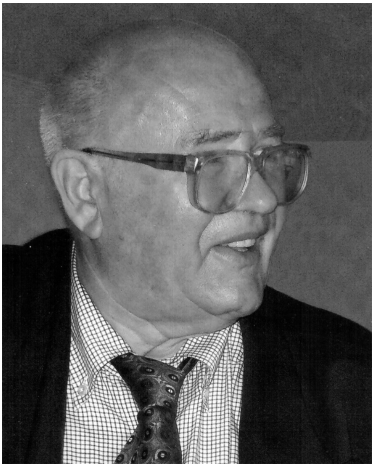

Konstantin Aleksandrovich Gridnev was born on February 8, 1938 in Sevastopol and in his childhood he experienced all the horrors of war. Later he entered the physical faculty of Leningrad (now St.Petersburg) State University. All his active life was connected with alma mater, where he advanced from a student to the department head. K.A. Gridnev always endevoureded to develop the most promising research areas in nuclear physics. He was a prominent scientist, an outstanding organizer of International Conferences on Nuclear Physics and Nuclear Structure, Professor, Doctor of Science. While still a post-graduate student, he understood the opportunities provided by the newborn computers and developed the program packages for calculations of direct nuclear processes. These programs were widely used in the major nuclear physics centers. Later K.A. Gridnev focused on theoretical studies of nuclear structure and nuclear reaction mechanisms. He got a lot of new interesting results, among which one might mention investigation of transfer reactions to unbound states in nuclei, application of the nonlinear Schrödinger equation to nuclear physics. Konstantin Aleksandrovich made a great contribution to the studies of neutron drip line, Bose condensation and clustering processes in atomic nuclei. He was the author of more than 150 publications. These works were highly appreciated by scientific community and are often cited in the literature.

For more than 25 years Konstantin Aleksandrovich headed the Department of nuclear physics and prepared 5 Doctors of Science and 37 PhD’s. His lectures were attended by students and professionals in more than 10 countries. His personal qualities caused a feeling of profound sympathy among all those who communicated with him.

Konstantin Aleksandrovich has played an important role in the development of scientific relations between Russia and international nuclear centers in many countries. He represented Russia in the Board of the Nuclear Physics Division of the European Physical Society, was a member of the editorial boards of several international journals.

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Theory of Atomic Nucleus and Fundamental Interactions

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DISCOVERY OF ELEMENTS 113–118 AND PROSPECTS FOR THE INVESTIGATION OF SUPERHEAVY NUCLEI

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Discovery and investigation of the "Island of stability" of superheavy nuclei (SHN) at the separator DGFRS in the ^{238}U–^{249}Cf+^{48}Ca reactions is reviewed [1, 2]. The results are compared with the data obtained in chemistry experiments and at the separators SHIP, BGS, TASCA, and GARIS. The synthesis of the heaviest nuclei, their decay properties, and methods of identification are discussed. The increased role of shell effects in the stability of superheavy nuclei with rise of their neutron number is demonstrated by comparison of the experimental results with empirical systematics and theoretical data.

At present, the region of known SHN with $Z \leq 118$ and their α-decay descendants forms a relatively narrow "ridge" in the nuclear landscape. In order to more fully understand the role of shell stabilization in this region, it is essential to considerably extend the area of synthesized SHN. Recent achievements and prospects for the production of the heaviest elements are discussed (Fig. 1).

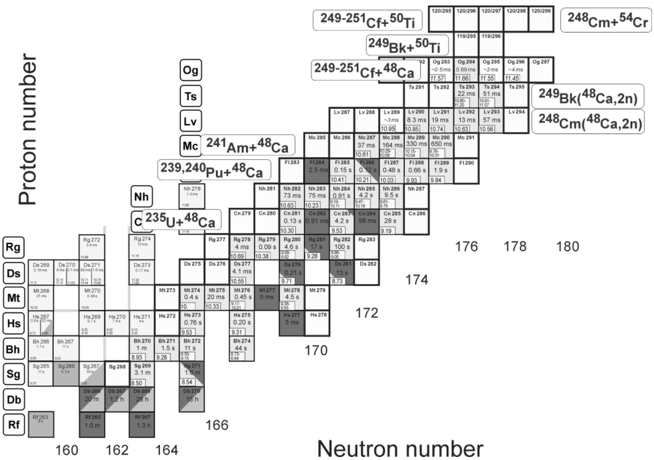

Fig. 1. Summary decay properties of the isotopes of elements with $Z \geq 104$ and $N \geq 159$. The average energies of α particles and half-lives are given for α emitters (grey squares). For spontaneously fissioning nuclei marked by dark grey squares the half-lives are listed. Nuclei synthesized in the reactions of ^{48}Ca with ^{238}U–^{249}Cf target nuclei are shown by more bright colour. New nuclides that could be synthesized in the given reactions are shown by open squares.

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PECULIARITY OF NUCLEAR REACTIONS INDUCED BY LOOSELY BOUND CLUSTER NUCLEI

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Reactions involving loosely bound nuclei have many special features that have vigorously been discussed in recent years in a number of studies (for example, [1]). These features include the enhancement of interaction cross sections in the subbarrier energy region. This effect is especially pronounced for clustering nuclei (for example, ^{6,7,9,11}Li) [2], as well as neutron-halo nuclei (for example, ^{6,8}He) [3]. Transfer, breakup, and complete fusion reactions are dominant interaction channels for such nuclei. Processes in which the breakup of loosely bound nuclei in the field of a heavy nucleus is followed by the fusion of the residual nucleus with the target nucleus have been the subject of numerous theoretical and experimental investigations.

Excitation functions are measured for complete-fusion, total cross section and transfer reactions induced by the interaction of d, ^{6,8}He and ^{6,9,11}Li with ^{206}Pb, ^{209}Bi, and Pt. Data obtained for fusion reactions induced by ^{6,8}He ions deviate from the predictions of the statistical model of compound-nucleus decay at projectile energies in the vicinity of the Coulomb barrier height. A strong enhancement of cross sections for fusion reactions induced by the interaction of ^{6,8}He with target nuclei is observed. The cross sections for reactions of cluster transfer, neutron transfer from $^{3,\,6,\,8}$He, and deuteron transfer from ^{6,9}Li at deep sub barrier energies are also found to be enhanced. These results are discussed from the point of view of the effect of the cluster structure of nuclei on the interaction probability at energies in the vicinity of the Coulomb barrier height [4].

The energy dependence of total cross sections of reactions ^{6}He + Si and ^{6,9,11}Li + Si in the beam energy range 5 ÷ 40 A·MeV has been measured. For the reactions ^{9,11}Li + Si new data in the vicinity a local enhancement for 20 A·MeV of the total cross section was obtained. Theoretical analysis of possible reasons of appearance of this peculiarity in the collisions of nuclei ^{6,8}He and ^{9,11}Li with Si nuclei has been carried out including the influence of external neutrons of weakly bound projectile nuclei [5].

The results of the present study are of paramount importance for solving astrophysical problems — in particular, for obtaining deeper insight into the mechanism of the production of light elements in the Universe.

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THE DETERMINATIVE ROLE OF THE INTERFERENCE EFFECTS IN THE DESCRIPTION OF THE *T*-ODD ASYMMETRIES IN THE REACTIONS OF TERNARY FISSION OF NUCLEI BY COLD POLARIZED NEUTRONS

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In the framework of the quantum theory of fission [1, 2], the coefficients of *T*-odd asymmetries in the differential cross sections for reactions of the actinide nuclei ternary fission by cold polarized neutrons with the flight of both prescission and evaporation third particles have been built taking into account the influence of the compound fissile system rotation through the Hamiltonian of the Coriolis interaction H^{cor} on the angular distributions of the named above third particles and fission fragments:

$$D(\Omega)=\frac{d\left\{A^0_{\text{odd}}(\theta)\right\}}{d\theta}\frac{\cos\varphi}{\left\{A^0(\theta)\right\}}(\Delta\theta)_{\text{odd}}+\frac{d\left\{A^0_{\text{ev}}(\theta)\right\}}{d\theta}\frac{\cos\varphi}{\left\{A^0(\theta)\right\}}(\Delta\theta)_{\text{ev}}, \qquad (1)$$

Where $\{A^0_{\text{odd}}(\theta)\}$ and $\{A^0_{\text{ev}}(\theta)\}$ are the main values of odd and even components of amplitudes $A^0(\theta)$ of the third particle angular distributions unperturbed by rotation [2] and $(\Delta\theta)_{\text{odd(ev)}}$ are the effective turning angles for ternary particle flight direction relatively to light fission fragment flight direction, which are constructed taking into account the interference of the fission amplitudes of the various neutron resonances sJ_s and $s'J_{s'}$. The quantity $\sin(\delta_{sJ_s}-\delta_{s'J_{s'}})$, that depends on the phase difference $\left(\delta_{sJ_s}-\delta_{s'J_{s'}}\right)$ of the interfering neutron resonance states sJ_s and $s'J_{s'}$ and is included in the determination of the turning angle of the fission fragments flight direction, vanishes for using of the classical method of trajectory calculations [3], in which the interference of various neutron resonances $sJ_s \neq s'J_{s'}$ is not taken into account.

Since for evaporation γ-quanta and neutrons the turning angle $(\Delta\theta)_{\text{odd}}$ vanishes because of the even character of the amplitudes $A^0(\theta)$ of these particles angular distributions and the turning angle $(\Delta\theta)_{\text{ev}}$ is determined only by the turning angle of the fission fragments flight direction proportional to the quantity $\sin(\delta_{sJ_s}-\delta_{s'J_{s'}})$, the coefficient of odd asymmetry (1) vanishes in the case of using the classical method of trajectory calculations [3], in which the interference of various neutron resonances $sJ_s \neq s'J_{s'}$ is not taken into account.

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NEW *NN* INTERACTION BASED ON CHIRAL EFFECTIVE FIELD THEORY FOR DESCRIPTION OF LIGHT NUCLEI

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I discuss properties of a recently suggested *NN* interaction Daejeon16 [1]. This interaction is tied to QCD since it is derived from the Idaho *NN* interaction [2] which has been obtained within the chiral effective field theory in the next-to-next-to-next-to leading order (N3LO) approximation. The Idaho N3LO *NN* potential was transformed using the Similarity Renormalization Group (SRG) technique to improve the convergence of many-body calculations within various *ab initio* approaches like the No-core Shell Model (NCSM). Next this SRG-evolved interaction was phase-equivalently transformed to describe binding energies, spectra and other observables in *p*-shell nuclei without explicit use of three-nucleon (*NNN*) forces.

The Daejeon16 *NN* interaction is shown to provide a rapid convergence of the NCSM calculations and a very good description of the *p*-shell nuclei, a more accurate than the previous version of our *NN* interaction JISP16 [3] reducing the need for *NNN* forces. This interaction was used to obtain an effective interaction between valence nucleons in the *sd* shell in the standard shell model with a core using the technique described in Ref. [4] and to calculate resonant states in light nuclear systems, e. g., in the tetraneutron, using the methods suggested in [5, 6].

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ABOUT TERNARY FISSION OF NUCLEI INDUCED BY NEUTRONS

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Rotational effects of the fissioning nucleus ^{234}U at scission point were measured in ternary and binary fission of ^{233}U nuclei using polarized *s*-neutrons. It was found that in ternary fission the fissioning nucleus rotates to the right relative to the direction of the polarized neutrons beam [1], whereas in binary fission of the same nucleus, it rotates in the opposite direction [2]. Moreover, the ternary fission "prefers" the spin states $J = I + 1/2$ [3]. This phenomenon cannot be explained within the existing concepts of the ternary fission as one of the two "finite states" after rupture of the neck. The same "parent" nucleus ^{234}U cannot rotates in opposite directions for two different final states. It is necessary to assume inevitably [4] that the ternary fission is a special branch of descent from the saddle point to the scission. It is formed on the saddle in the configuration favorable for the formation of clusters. Why, it "prefers" the spin state $J = I + 1/2$? This is an interesting question for further investigation.

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FIRST EXPERIMENTS AT THE NEW FRAGMENT SEPARATOR ACCULINNA-2

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[9] All-Russian Research Institute of Experimental Physics, Sarov, Russia;
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In 2017 the first set of radioactive ion beams (RIBs) was obtained from the new in-flight fragment separator ACCULINNA-2 [1] operating at the primary beam line of the U-400M cyclotron [2]. Observed RIB characteristics (intensity, purity, beam spots in all focal planes) were in agreement with estimations. The new separator provides high quality secondary beams and it opens new opportunities for experiments with RIBs in the intermediate energy range 10÷50 A·MeV [3].

The ^{6}He+d experiment, aimed at the study of elastic and inelastic scattering in a wide angular range, was chosen for the first run. The data obtained in the ^{6}He+d scattering, and in the subsequent measurements of the ^{8}He+d scattering, are necessary to complete MC simulation of the flagship experiment: search of the enigmatic nucleus ^{7}H in the reactions d(^{8}He,^{3}He)^{7}H and p(^{8}He,pp)^{7}H with higher precision in comparison with pioneering works [4, 5].

Opportunities of day-two experiments with RIBs using additional heavy equipment (radio frequency filter, zero angle spectrometer, cryogenic tritium target) will be also reported. In particular, the study of several exotic nuclei ^{16}Be, ^{24}O, ^{17}Ne, ^{26}S and its decay schemes are foreseen.

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INFLUENCE OF THE STRUCTURE OF LIGHT WEAKLY BOUND NUCLEI ON THE BEHAVIOR OF NUCLEAR REACTIONS

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Reactions involving light atomic nuclei have been of particular interest. In light nuclei with a large (small) *N*/*Z* ratio, a neutron (proton) surface weakly bound layer responsible for the halo structure was observed. All these features of the structure of light nuclear projectiles affect their participation in nuclear reactions.

The report analyzes the results of experiments on the study of cross sections for fusion and transfer reactions using beams of weakly bound (^{3}He), cluster (^{6}Li, ^{7}Li), and halo (^{6}He, ^{8}B) nuclei by bombarding nuclei of light and heavy elements. In reactions involving weakly bound nuclei, we identified specific behavior peculiarities of the formation cross sections of evaporating recoiling nuclei in fusion reactions and the transfer reaction products at energies close to the Coulomb barrier [1]. In particular, an increase in the cross sections of fusion and transfer reactions with halo nuclei in near-barrier energy regions was observed. The cross sections of neutron or light cluster transfer reactions involving halo and cluster nuclei reached their maximum at the energy close to the Coulomb barrier [2].

The report also analyzes the influence of various channels of nuclear reactions involving these light nuclear projectiles on the population of the ^{44m}Sc (6^{+}), ^{195m}Hg and ^{197m}Hg ($7/2^{-}$), ^{198m}Tl and ^{196m}Tl (7^{+}), ^{196m}Au and ^{198m}Au (12^{-}) isomeric nuclear states. The behavior of excitation functions and high isomeric ratios (σ_m/σ_g) for the products of nuclear reactions proceeding through a compound nucleus and followed by neutron evaporation were explained within compound nucleus models. The reactions accompanied by neutron and proton transfer are as a rule characterized by low isomeric ratios whose behavior depends on the type of direct reactions (stripping versus pick-up reactions) and varies as the energy changes. The reactions involving charged particle emission and cluster transfer result in intermediate values of isomeric ratios.

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PARTICLE-HOLE DISPERSIVE OPTICAL MODEL FOR GIANT RESONANCES

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The physical content, unique features and some implementations of the newly developed particle-hole dispersive optical model (PHDOM) [1] are briefly presented. Within the model, the main modes of damping a great variety of high-energy (*p*-*h*)-type excitations (including giant resonances) in medium-heavy mass spherical nuclei are commonly described. Being formulated in terms of the energy-averaged *p*-*h* Green function, the model is a microscopically-based extension of the standard and non-standard continuum-RPA versions to phenomenological consideration of the spreading effect. The latter is described in terms of the strength of the energy-averaged specific *p*-*h* interaction (*p*-*h* self-energy term). The imaginary part of this strength determines the real one via a dispersive relationship, which follows from the spectral expansion of the 2*p*-2*h* Green function. Supposing that different *p*-*h* states are “decaying” into chaotic states independently of one another, one gets the model equations in a closed form. Weak violations of the model unitarity, which are due to the methods used for describing the spreading effect, were examined and ways for unitarity restoration were proposed [2]. The unique features of the PHDOM are concerned with its ability to describe: (i) the energy-averaged double transition density and, as a result, various strength functions at arbitrary (but high-enough) excitation energies, including giant resonances; (ii) direct one-nucleon decay of (*p*-*h*)-type excitations; (iii) the shift of resonance-like structures related to mentioned excitations due to the spreading effect. In first implementations of the PHDOM, the following input quantities are used: the Landau-Migdal *p*-*h* interaction, a partially self-consistent phenomenological mean field, properly parameterized the imaginary part of the strength of the *p*-*h* self-energy term. The intensity of this part is, actually, only one specific model parameter taken from the description of the observable total width of a given giant resonance. Some implementations of the PHDOM current version to the description of simplest photo-nuclear reactions [3], isoscalar [2, 4], and charge-exchange (isovector) [5] monopole excitations are briefly presented.

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NUCLEAR CLUSTERING IN AB INITIO CALCULATIONS

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A formalism, adopted to investigate the (*A*+*X*)-nucleon states containing weakly bound nucleon or cluster as well as cluster decay channels, making possible the use of realistic, based on quantum chromodynamics, *NN* and *NNN*-potentials, is devised. A building block of the approach is a basis incorporating both No-core Shell Model wave functions and translationally-invariant wave functions of various cluster channels which are also presented in the shell-model form. Thus the approach is an attempt to follow the general idea formulated in [1] – a unified theory of the nucleus and nuclear reactions. It is convenient for ab initio calculations of cluster form factors and spectroscopic factors too.

The results of computations of the total binding energies of light nuclei and spectra of their low-laying states as well as the spectroscopic factors of various cluster channels are presented. This rigorous study reveals that the contribution of "non-clustered" components to the total binding energy is great even in the typical example of cluster systems such as ^{7}Li and ^{8}Be nuclei.

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DEVELOPMENT OF ACTIVE CORRELATION METHOD FROM THE VIEWPOINT OF 2018 YEAR COMMISSIONING OF SHE FACTORY OF FLNR (JINR)

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The Dubna Gas-Filled Recoil Separator is the mostly advanced facility in the field of synthesis of superheavy nuclei. Namely with this facility new Z = 114 to 118 (Fl to Og) elements were discovered using ^{48}Ca intense beam. The experiments like Actinide target + ^{48}Ca → SHN + xn are under consideration from the viewpoint of original instruments and methods application. With a nearest future commissioning of SHE Factory (DC-280 super intense cyclotron) of FLNR (JINR) the experiment with ^{50}Ti projectiles at the new gas-filled recoil separator is planned in 2019. Stronger requirements to the detection system as well as to the active correlated method are under consideration [1–5].

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RESONANCE STRUCTURE OF THE CHARGE-EXCHANGE STRENGTH FUNCTION

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The charge-exchange states are connected with the charged branch of excitations and corresponds to excited states of isobaric nuclei $A(N–\Delta Q, Z+\Delta Q)$ with charge $\Delta Q = \pm 1$. They manifested in the corresponding charge-exchange reactions, for example (ν,e), (p,n), (n,p), (^{3}He,t), (t,^{3}He), (^{6}Li, ^{6}He) etc., or in β-transitions of nuclei and the processes accompanying the β-decay of nuclei. Among these states, collective resonance excitations are of the most interest. The theoretical investigation of these collective states began with the first calculations of the giant Gamow-Teller resonance (GTR) [1] and other collective states [2] long time before their experimental studies in the charge-exchange reactions with $\Delta Q = +1$ [3, 4]. Below the GTR is lying the isobaric analog resonance (AR), and even lower, the so-called, pigmy resonances (PR) [5], which are important in the charge-exchange reactions [6, 7].

The energies and matrix elements of the excited states that determine the structure of the charge-exchange strength function $S(E)$ were calculated both in the self-consistent theory of finite Fermi systems (TFFS), and in its approximate model version. The energy differences between the GTR and AR – $\Delta E_{\text{G-A}}$ were calculated and it is shown that the value of $\Delta E_{\text{G-A}}$ tends to zero in heavier nuclei, demonstrating the restoration of Wigner SU(4)-symmetry [8]. Using the same method the energies of pigmy resonances for nine isotopes of tin were calculated [5]. Comparison of the calculations with the experimental data on the energies of the charge-exchange resonances gives the standard deviation $\delta E < 0.50$ MeV, which is comparable with the experimental errors. Comparison of the calculated and experimental strength functions $S(E)$ also shows their similarity.

Further investigation of the resonant structure of the strength functions $S(E)$ will allow us to analyze the data of the charge exchange processes.

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CONNECTION OF EXPERIMENTAL CHARACTERISTICS OF *P*-EVEN *T*-ODD ASYMMETRIES FOR TERNARY FISSION OF NUCLEI BY COLD POLARIZED NEUTRONS WITH TRIPLE AND QUINARY SCALAR CORRELATIONS

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Using the methods of quantum fission theory [1, 2], it is proved that any *P*-even *T*-odd asymmetries in the differential cross sections of ternary fission reactions for non-oriented target nuclei by cold polarized neutrons in the first order on the neutron polarization vector $\vec{\sigma}_n$ can be represented through combinations of triple $B_3(\vec{\sigma}_n[\vec{p}_{LF},\vec{p}_{TP}])$ and quinary $B_5(\vec{\sigma}_n[\vec{p}_{LF},\vec{p}_{TP}])(\vec{p}_{LF},\vec{p}_{TP})$ scalar correlations, which depend on the vector $\vec{\sigma}_n$, determining the direction of Y axis of the LCS, the unit vector of the light fission fragment momentum $\vec{p}_{LF}$, determining the direction of Z axis of the LCS, and the unit vector of the third particle momentum $\vec{p}_{TP}$, determining of the third particle flight direction by the solid angle $\Omega(\theta,\varphi)$, and coefficients B_3 and B_5, defined by quantities $(\vec{p}_{LF}, \vec{p}_{TP})^n$ with even n = 0, 2, ... Then the coefficients $D(\theta,\varphi)$ of named above asymmetries can be represented

$$D(\theta,\varphi) = D_3(\theta,\varphi) + D_5(\theta,\varphi) = B_3(\vec{\sigma}_n[\vec{p}_{LF},\vec{p}_{TP}])/P(\theta) + B_5(\vec{\sigma}_n[\vec{p}_{LF},\vec{p}_{TP}])(\vec{p}_{LF},\vec{p}_{TP})/P(\theta), \quad (1)$$

where $P(\theta)$ is the angular distribution of the third particle for the ternary fission of nuclei by unpolarized neutrons. Using the symmetry properties of the introduced in formula (1) correlations, one can find formulas for the experimental coefficients $D_3^{exp}(\theta,\varphi=0)$ and $D_5^{exp}(\theta,\varphi=0)$, corresponding to the indicated correlations, through the experimental values of the coefficient $D^{exp}(\theta,\varphi=0)$ and of the angular distribution $P^{exp}(\theta)$:

$$D_{3,5}^{exp}(\theta,\varphi=0) = [D^{exp}(\theta,\varphi=0)\, P^{exp}(\theta) \pm D^{exp}(\pi-\theta,\varphi=0)\, P^{exp}(\pi-\theta)] \,/\, (2P^{exp}(\theta)). \quad (2)$$

Using in formula (2) of the coefficients $D^{exp}(\theta,\varphi=0)$ for the target nuclei ^{233}U, ^{235}U, ^{239}Pu and ^{241}Pu [3] and distributions $P^{exp}(\theta)$ of prescission α-particles it can be calculated the experimental coefficients $D_3^{exp}(\theta,\varphi=0)$ and $D_5^{exp}(\theta,\varphi=0)$. It turned out that the signs of $D_5^{exp}(\theta,\varphi=0)$ for the target nuclei ^{235}U, ^{239}Pu and ^{241}Pu are positive for $\theta < \pi/2$ and negative for $\theta > \pi/2$, while the sign of $D_5(\theta,\varphi=0)$ for ^{233}U is negative at $\theta < \pi/2$ and positive at $\theta > \pi/2$. This result agrees with the calculation of the coefficient $D_5(\theta,\varphi=0)$ in the framework of the quantum fission theory [4] and is in contradiction with results based on the trajectory calculation method [3], for which the signs of the coefficients $D_5(\theta,\varphi=0)$ are positive for all target nuclei.

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MEASUREMENT OF *T*-ODD EFFECTS IN THE NEUTRON INDUCED FISSION OF ^{235}U AT A HOT SOURCE OF POLARIZED RESONANCE NEUTRONS

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The TRI effect was first discovered in the ternary fission in a series of experiments performed at the ILL (Grenoble) reactor by a collaboration of Russian and European institutes and carefully measured for several fissioning nuclei. Later, the ROT effect has been observed in the emission of prompt gamma rays and neutrons in fission of ^{235}U and ^{233}U, although its value was an order of magnitude smaller than in the α-particle emission from ternary fission. All experiments performed so far were done with cold polarized neutrons, what assumes a mixture of several spin states, the weights of these states are not well known. The present paper describes the first attempt to get "clean" data by performing the measurement of gamma and neutron asymmetries in an isolated resonance of ^{235}U at the POLI instrument of the FRM-2 reactor in Garching.

PERSPECTIVES OF DEVELOPMENT OF RADIATION TECHNOLOGIES IN RUSSIA

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As is known, high-tech radiation technologies have become an integral part of human life precisely because of their universality – they are now used in many industrial sectors, agriculture, medicine, etc.

Applications of radiation technologies are quite extensive: nuclear energy, nuclear medicine (radiodiagnosis and radiotherapy), industry and construction (modification of the properties of materials, development of new materials, sterilization products, inspection, production of radiopharmaceuticals), agriculture (disinfestation of grain products processing for prolongation of storage terms, increase of germination of seeds), solution of environmental problems (treatment of flue gases of coal-fired power plants, sewage treatment, decontamination of polluted terrains thorium), and much more. The total number of sources of ionizing radiation used in the world is more than 14 million units. The main part of which are *X*-ray tubes (~4 million units) and radioactive sources of various types (~10 million units). As well as high-tech diagnostic facilities (more than 94000 units) and radiotherapy (~20000 units).

In Russia, now, there are more than 147000 sources of ionizing radiation, including equipment and devices using radioactive sources (~87600 units), *X*-ray units (~58600 units), charged particle accelerators (~473 units) and reactors (~140 units).

The cost of products manufactured using radiation technology exceeds $500 billion per year. The rate of appearance and spread of high-tech radiation technologies in various sectors is extremely high, and their number doubles approximately every seven years.

NONPROLIFERATION REGIME AND EXPORT CONTROL

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The article outlines the barriers needed to prevent the threat of proliferation of nuclear weapons. The most important barriers are the Treaty on the Non-Proliferation of Nuclear Weapons, the IAEA safeguards system and the guidelines of the Zangger Committee and the Nuclear Suppliers Group.

The monitoring principles of switching of nuclear materials from peaceful use to military are basic and applicable to nuclear power both on thermal and fast neutrons.

ROLE OF THE HEAVY STRIPPING MECHANISM IN THE FORMATION OF α-PARTICLES ANGULAR DISTRIBUTION IN ^{27}Al (p,α)^{24}Mg REACTION

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In Nilsson's model it is possible to consider ^{24}Mg as 8 d-nucleons at $d_{5/2}$ shell, ^{27}Al (^{23}Na) – as hole states in this shell with positive quadrupole deformation (β_2 = +0.25 for ^{27}Al and +0.4 for ^{24}Mg, ^{23}Na) [1]). Earlier in [2] we calculated α-particles angular distribution at ^{27}Al(p,α)^{24}Mg reaction for triton direct pickup mechanism. However, it was not possible to adequately describe the region of large angles, where a considerable increase in the cross section.

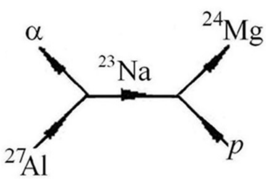

Fig. 1. Diagram illustrating of heavy ^{23}Na *cluster transfer.*

In this work the mechanism of a heavy stripping of ^{23}Na cluster is considered (Fig. 1).Calculation of this mechanism cross section is carried out by FRESCO code [3], the spectroscopic amplitudes (SA) were calculated within Nilsson's model. The received cross sections for levels 0^+ and 2^+ of ^{24}Mg final nucleus less than the experimental ones on several orders and has also no expressed maximum in a back hemisphere. Anomalously small SA of ^{27}Al → ^{23}Na + α can explain such behavior of heavy cluster stripping mechanism contribution at least qualitatively. SA value is influenced by a weak overlap of ^{27}Al and ^{23}Na wave functions (WF) in Nilsson's model. At significantly different deformation of these nuclei their overlap amplitude is 0.23. But even more the generalized Talmi's coefficient (TC) $K_\alpha(d^4 : l)$ which transfers WF of four nucleons with principal quantum number of N = 8 and orbital moment l to α-particle WF with $N = l = 0$ reduces SA. The TC value changes depending on l, but does not exceed 0.05. As a result the top assessment of multiplication of SA ^{27}Al → ^{23}Na + α ⊗ ^{24}Mg → ^{23}Na + p makes 10^{-2}. So the SA small values also lead to the fact that a contribution of heavy ^{23}Na cluster transfer mechanism in angular distribution of protons in ^{27}Al(p,α)^{24}Mg reaction is underestimated in comparison with an experiment by several orders. It means that heavy ^{23}Na cluster transfer mechanism does not play essential role in transfer reactions of nucleons on $d_{5/2}$ shell.

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CHARGE PARTICLE FORMATION IN STOPPED PION ABSORPTION BY NUCLEI

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Spectra of charged particles (p, d, t, ^{3,4}He) formed in reactions of stopped pion absorption by nuclei were measured on pion channel of PNPI synchrocyclotron using semiconductor spectrometer [1]. Data were obtained on 17 targets in the mass range $6 < A < 209$. In order to analyze the data we developed a phenomenological model, that allowed describe spectra and yields of the particles formed on light, intermediate and heavy nuclei.

Within the framework of the proposed model there are considered three stages of absorption reaction – primary absorption on intra-nuclear clusters, pre-equilibrium stage and evaporation. *A*-dependences of particle yields are obtained for each stage of the reaction. The proposed empirical formulas allow extend the obtained results to nuclei with an arbitrary number of protons and neutrons.

There are considered the contributions of different mechanisms (cluster absorption, knock-out, pick-up and evaporation) in the formation of protons and complex charged particles. The contribution of absorption on a pp in the formation of protons is about 20% of full yield It is shown, that ratio of elementary widths of pion absorption on pn- and pp-pairs does not depend on the atomic number of the target and is equal 3.5 ± 0.3. Role of pion absorption on various clusters (pp, ^{3,4}He) were estimated. The contribution of primary absorption to the formation of complex particles is 20% for deuterons, 5% for tritons and less than 5% for helium isotopes.

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FUTURE OF THE NUCLEAR POWER

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The idea of using accelerator beams for nuclear energy plants was already discussed in 50-ies of the previous century. The concept of the power amplifier assumes forming neutron fluxes in the processes of interaction between the n, p and e^- beams extracted from the accelerator. This scheme was accepted to call the electronuclear method of obtaining the energy or ADS (Accelerator Driven System) [1].

This method in the atomic energy was based on the fission of the heavy nuclei ^{235}U, ^{238}U, ^{232}Th in subcritical systems being controlled by external sources of charged particles p, n, e^-. The electronuclear method includes obtaining the flux of thermal neutrons being produced while irradiating the n, p, e^- prolonged targets made of Pb, Bi or U, placed in the centre of the blanket. The formed flux of thermal neutrons in its turn stimulates deletion of uranium nuclei in them while irradiating "the cooled" thermal elements (twels).

Numerous experiments have been performed at the subcritical system (YALINA – D) by using the proton beam of the Dubna phasotron at the energy of 660MeV. The uranium subcritical polyethylene assembly (maximum multiplication coefficient $K_{eff} \approx 0.975$) is a cube with the side 120cm long.

The assembly is mounted from polyethylene cubes with the ready-made channels to place the twels located in the rectangular cell with the gap equal to 20mm. In the centre of the assembly there is a neutron producing target, Pb (80 mm × 80 mm × 580 mm). In the active zone of the subcritical system there are specialized experimental channels of ∅20мм to locate the targets (including also the radioactive ones) and the channels for monitoring the neutron flux density.

The article proves the opportunity of constructing the subcritical systems being controlled by the beams of charged particles of the energy from 14 MeV till 1 GeV with the coefficient of using twels from 5% till 50% and higher.

It is necessary to stress the creative potential of the advanced technological approaches to the future of nuclear energy. Subcritical systems are prototypes of a new generation of safe and waste-free mini Nuclear Power Plants.

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ELASTIC AND INELASTIC SCATTERING OF α-PARTICLES BY ^{20}Ne NUCLEI AT ENERGY OF 48.8 MeV

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At isochronous cyclotron U-150M of the Institute of Nuclear Physics (Almaty, Kazakhstan), the differential cross sections for the elastic and inelastic scattering had been measured at the energy of 48.8 MeV with excitation of low-lying states of the ^{20}Ne nucleus. The experimental angular distributions are presented in Fig. 1.

The data for transitions to the ground (0^+) and excited (E_x = 1.63 MeV (2^+), E_x = 4.25 MeV (4^+)) states relating to the ground state band were analyzed in the framework of the optical model and the coupled-channels method based on rotational model. It was shown that the analysis is sensitive not only to the magnitude, but also to the sign of the quadrupole and hexadecapole deformations. The extracted values of the parameters β_2 = 0.54 ± 0.14 and β_4 = 0.17 ± 0.06 are in good agreement with the results of other experiments on the scattering of protons, ^{3}He and α-particles and correspond to the data known from the electron scattering and Coulomb excitation.

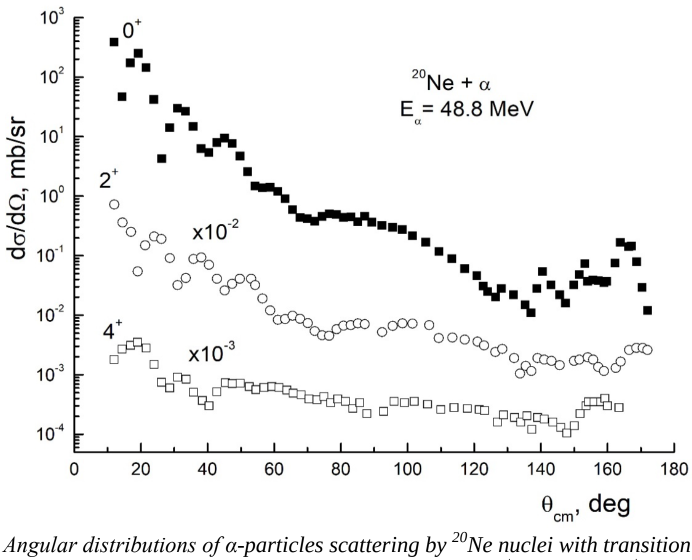

Fig. 1. Angular distributions of α-particles scattering by ^{20}Ne nuclei with transition to the ground and excited states with excitation energies 1.63 (2^+) and 4.25 (4^+) MeV.

CALCULATION AND COMPARISON OF KEY PARAMETERS CHARACTERIZING THE MAGNETO-INERTIAL FUSION

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At present, most of the magnetic fusion community effort is devoted to designing and constructing a fusion power plant (FPP). But taking into account the well-developed nuclear power industry, in the 21st century it is unlikely to oppose of FPP to nuclear power plant. In this connection it is necessary to find new and beneficial ways of using thermonuclear neutrons. They can perform the role of driver for the subcritical nuclear system – hybrid nuclear fusion-fission reactor, in the first place. Such a system could also be used for the transmutation of long-lived radioactive waste and generation of nuclear fuel for auxiliary systems. Compact configuration based on the field-reversed configuration (FRC) has been well studied for this purpose. Features of the neutron source, potential treatment of radioactive nuclear waste and generation of nuclear fuel in the breeding blanket are presented in several papers.

Alternative concepts and confinement systems [1–9], e.g. magneto-inertial fusion (MIF), and low radioactive (aneutronic) fuels may not only have the above-mentioned applications, but also used in other areas. Currently, they are already being used as a source of protons and neutrons in materials technology for the study of plasma-wall interaction, to test the most basic elements of the loaded designs and can be used in ITER and DEMO. The use of helium-3 plasma is boundless and can lead to a new era in medicine and space exploration. Applications of high-temperature FRC plasma, using deuterium and helium-3 (D-^{3}He), proton and boron-11 (p-^{11}B), proton and isotope of lithium (p-^{6}Li) reactions and catalyzed cycles on the basis of these reactions, for example D-^{3}He-^{6}Li, which are already being implemented or will be implemented in the near future – a proton source, feeding of fuel in the form of a FRC or spheromak, detection of explosives and chemical waste, cancer therapy and the production of medical isotopes.

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RESULTS OF THE MICROSCOPIC SELF-CONSISTENT THEORY OF QUASIPARTICLE-PHONON INTERACTION IN NUCLEI

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The problem of inclusion of the quasiparticle-phonon interaction (QPI) into microscopic nuclear theory has a long story. However, the self-consistent approach in this problem, which was developed within the modern many-body nuclear theory based on the Green function formalism [1, 2], gives a new quality: a great predictive power and absence of new or fitted parameters (which is principal for astrophysics), consistency and taking some new effects into account. In this work, a review of the recent results of this approach is given. They have been obtained within the Energy Density Functional theory with Skyrme or Fayans functionals both in the g^2 approximation, where g is the phonon creation amplitude, and without this approximation (tadpole effects).

We consider the following concrete problems: 1) electromagnetic moments of odd and odd-odd nuclei in the ground state, 2) second order anharmonic effects: quadrupole moments of the first 2^+ and 3^- states in Sn and Pb isotopes and *EL*-transitions between one-phonon states, 3) third order anharmonic effects, 4) pygmy-dipole resonance: fine structure, contribution to radiative nuclear reaction characteristics, 5) giant resonances: widths problem, development of newest self-consistent approaches. For magic and semi-magic nuclei, we discuss additional observed QPI effects and structures in nuclear characteristics (for giant resonances, the structures have been obtained earlier within the non-self-consistent Quasiparticle-Phonon Model), new (i.e. three-quasiparticle and four-quasiparticles) ground states correlations, comparison of the results with various functionals, explanation due to QPI of newest experiments including those for neutron-rich Ni isotopes etc. We have predicted many unknown values of nuclear characteristics.

It is shown that in all considered problems, contribution of QPI is considerable or important in principle, and necessary to explain experimental data.

The results have been published in about 70 articles within last 5–7 years in Russian and mainly in English.

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ALPHA DECAY MODEL OF SPHERICAL NUCLEUS IN SYNCHROTRON RADIATION FIELD

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In Ref. [1], we investigated the possibility of modifying alpha decay rate by the influence of a laser radiation upon a nucleus. We showed that the laser radiation with the extreme achievable intensity slightly modifies the total rate of alpha decay. A different result may be probably obtained if the synchrotron radiation (SR) is used for the irradiation of an alpha-active nucleus. At present, SR from the third generation synchrotrons has high brilliance, the photon energy may reach 200–300 keV and, in the future, it may be larger. These energies are comparable with nuclear ones and the effect from the influence of the SR could be more significant.

For convenience sake, we singled out the two components in a direct influence of SR on alpha decay. In the first place, it is a change by an electromagnetic field of the potential barrier form through which an alpha particle surmounts in the decay process. For a laser field we considered this problem in Ref. [1]. The answer depends essentially on its intensity. For the alpha decay of the ^{238}U isotope, we showed that the relative enhancement of the decay rate is as small as 2% even at the limiting values of the radiation intensity of 10^{28} W/cm^2. The SR intensity is essentially smaller; therefore, the change of the alpha decay rate from the deformation of the potential barrier will be negligible.

In the second place, an interaction of SR and an alpha particle can substantially increase its energy because it is SR photons with 200–300 keV energies [2]. With an energy rise, the decay probability will be increasing as the potential barrier penetrability changes. Just this mechanism distinguishes the influence of SR and laser fields on the nuclear alpha decay (in the latter case the energy of the emitted particle does not practically change). In this mechanism we perform an estimation of the rate variation for the alpha decay of the ^{238}U nucleus ($Z = 92$, $E_\alpha = 4.27$ MeV) increasing the stated energy by 200 keV. We use the well-known one-particle Gamov model of alpha decay. The transition probability of the alpha particle into an excited state in the potential well under the influence of an electromagnetic field and the exposure duration of a nucleus by SR are taken into account. We show that it is necessary to irradiate the target by SR for nearly a year so that yield values of the alpha particles from ground and excited states become equal.

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THE CRITIQUE OF THE *T*-NULL THEOREM AND THE NEW APPROACH TO SEARCH OF THE *T*-INVARIANCE VIOLATIONS IN QUANTUM SYSTEMS

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In paper [1], taking into account the properties of the reaction matrix, associated only with conservation laws, the *T*-zero theorem has been prove that it is impossible to construct the any observed quantity that vanishes if *T*-invariance is conserved. However, since for all observables it is possible to determine the dynamic mechanisms of their appearance for the validity of the *T*-zero theorem it is necessary the absence of at least one *T*-invariant mechanism that leads to a nonzero value of any observable quantity.

As observable quantities it are selected the coefficients D^i_{ba} of asymmetries i with different *T*- and *P*-parity in the components of the differential cross sections $d(\sigma_i)_{ba}/d\Omega_b$ of binary reactions $a \to b$ with the participation of particles with momenta $\vec{p}_a$ and $\vec{p}_b$ and with oriented spins $\vec{S}_a$ and $\vec{S}_b$ in the initial a and final b reaction channels. For *T*-invariant quantum system it is possible to relate [2] the asymmetry coefficient D^i_{ba} for the initial reaction $a \to b$ with an analogous coefficient $D^i_{\bar{a}\bar{b}}$ for the time-reversed reaction $\bar{b} \to \bar{a}$ by formula:

$$D^i_{ba} = \varphi_i\left(\vec{p}_b, \vec{S}_b, \vec{p}_a, \vec{S}_a\right) = D^i_{\bar{a}\bar{b}} = \varphi_i\left(-\vec{p}_a, -\vec{S}_a, -\vec{p}_b, -\vec{S}_b\right), \qquad (1)$$

where the unified scalar function φ_i figures for the initial and time-reversed reactions in which the transition from the initial reaction $a \to b$ to the time-reversed reaction $\bar{b} \to \bar{a}$ is connected with the transformation of four arguments of type $\vec{p}_b \to -\vec{p}_a$, $\vec{S}_b \to -\vec{S}_a$, $\vec{p}_a \to -\vec{p}_b$, $\vec{S}_a \to -\vec{S}_b$. If function $\varphi_i\left(\vec{p}_b, \vec{S}_b, \vec{p}_a, \vec{S}_a\right)$ for all possible T-invariant mechanisms changes sign during the transition from the initial to the time-reversed reaction, equality (1) leads the relation $D^i_{ba} = 0$ that contradicts the *T*-zero theorem. Specific asymmetries with different *P* and *T* parities were found in the cross sections of the reactions of binary and ternary fission of nuclei, which can be used directly to detect the violation of *T*-invariance in nuclear systems.

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EXPERIMENTAL INVESTIGATIONS OF ATOMIC NUCLEUS PROPERTIES

FORMATION OF ROTATIONAL BANDS IN THE ^{9}Be NUCLEUS

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The differential cross-sections of the ^{9}Be(α,α)^{9}Be′ scattering at $E_{lab}(\alpha)$ = 90 MeV with excitation of ^{9}Be states 2.43 MeV, 2.78 MeV, 5.59 MeV and 7.94 MeV were obtained. The aim of this experiment was to determine the spin-parities of excited states of the predicted third rotational band in the ^{9}Be nucleus (2.78 MeV, 5.59 MeV, 7.94 MeV). We also used the data previously obtained in the experiment on the ^{9}Be(α,α)^{9}Be′ scattering at $E_{lab}(\alpha)$ = 30 MeV [1].

In [2] for excited states 2.78 MeV ($1/2^-$), 4.7 MeV ($3/2^+$), 5.59 MeV ($3/2^-$) and 7.94 MeV ($5/2^-$) were obtained new values of spin-parities J^{π} =$3/2^-$, $1/2^-$, $5/2^-$ and $3/2^-$, respectively. These values differ from the generally accepted ones [3].

It was shown that for the 2.78 MeV and 7.94 MeV states the spin-parity values are saved. For the 5.59 MeV state, we could not give an unambiguous answer about the change in spin-parity. In [4] the new excited state 3.82 MeV in the ^{9}Be was found with an assumed spin-parity $3/2^-$. It gives an opportunity to suppose that the 3.82 MeV state can be the second member of the predicted third rotational band replacing 5.59 MeV state.

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INVESTIGATION OF THE EFFECT OF COHERENT ELECTROMAGNETIC RADIATION BY RADIOACTIVE DECAY OF ^{152}Eu

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Some experiments, which have been carried out in the frames of "Energy and Transmutation" project and directed to solve tasks of studying the nuclear-physical processes' characteristics, ensuing on nuclei under the influence of coherent electromagnetic radiance, have been discussed in the report. The aim of the experiments [1, 2] is to study the mechanisms of influence of electromagnetic radiation of microwave range and laser radiation on the probability of the nuclear decay. A nuclear decay of ^{152}Eu, ^{137}Cs, ^{231}Th, ^{234}Th, ^{239}Np under the influence of laser radiances to their water solutions has been investigated. We have a great interest in studying a well-known and an investigated in details nucleus of ^{152}Eu.

The solution of ^{152}Eu has been under the influence of the laser radiance with wave length of radiation to 1064 nm, pulse repetition frequency to 10 Hz and energy in impulse to 700 mJ. Futher, we have used another laser, with wave length of radiation to 1064 nm, pulse repetition frequency to 10000 Hz and an energy in impulse 1 mJ. It is necessary to note that when we decrease a pulse repetition frequency to 1000 times, but increase the energy of the impulse to 700 times, the common tendency of the decreasing activity is kept (Fig. 1). These experimental data have been discussed in the report.

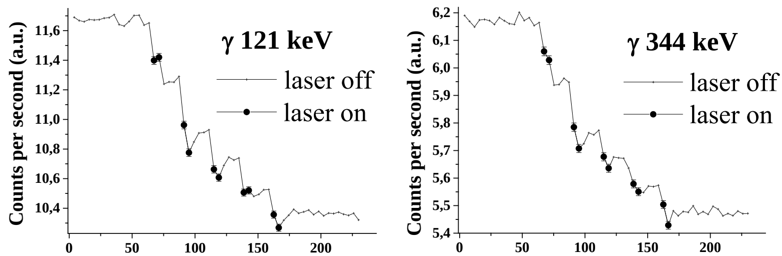

Fig. 1. The change in the intensity of the gamma 121 and 344 keV lines in ^{152}Eu.

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^{8}He SPECTROSCOPY IN STOPPED PION ABSORPTION BY ^{12,14}C

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The light neutron-rich nuclei lying in the vicinity of the drip line are interesting for the study of structure and properties of exotic nuclear states. The properties of these states are important for the development of nuclear models and refinement of the nucleon-nucleon potentials.

In present work, studies of the level structure of ^{8}He have been performed in the reaction of stopped pion absorption by ^{12,14}C nuclei. The experiment was carried out at the LANL with a two-arm semiconductor spectrometer of charged particles [1]. The formation of the ^{8}He was observed in the missing mass spectrum of the reactions $^{12}C(\pi^-, p^3He)^8He$, $^{14}C(\pi^-, t^3He)^8He$, $^{14}C(\pi^-, d^4He)^8He$. The measured MM (missing mass) spectrum of $^{14}C(\pi^-, d^4He)^8He$ reaction is shown in Fig 1. The ground state, excited state and contribution from reaction on impurities of ^{12}C are shown.

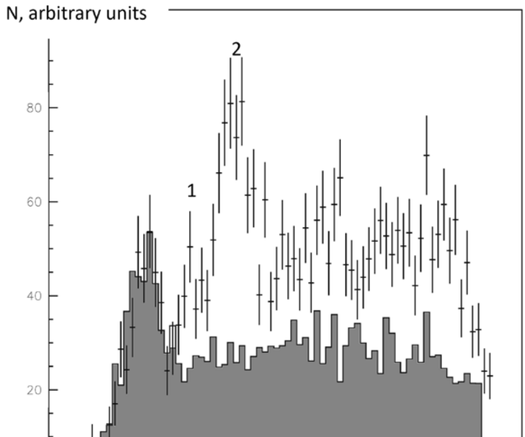

Fig. 1. MM spectrum in the reaction $\pi^- + ^{14}C \rightarrow d^4HeX$. Dots with error bars are the experimental data. Shaded histogram - contribution from reaction on impurities of ^{12}C. 1 – ground state, 2 – excited state.

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PHOTONUCLEAR REACTIONS ON PALLADIUM ISOTOPES

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The yields of photonuclear reactions on palladium isotopes were measured. The target from a natural mixture of palladium was subjected to irradiation of bremsstrahlung gamma quanta from the electron accelerator RTM-55 at a maximum energy of 55.6 MeV. To determine the yields of photonuclear reactions, the method of induced activity was used, which made it possible in one experiment to reliably separate and determine the yields of several reactions at once on individual isotopes of palladium.

The experimental procedure allows, in some cases, to separate the reactions with the formation in the final state of the isomeric or ground state. The small differences in the yields of photoneutron reactions are explained by the choice of the total photoabsorption cross section in theoretical calculations. Since reliable experimental data on the total cross section for photoabsorption on palladium isotopes are not available, theoretical calculations use data from systematics on neighboring nuclei. There is a significant difference with the experiment [1], in which the measurements were made on a bremsstrahlung beam, which may be due to the difficulties in restoring the reaction cross sections from the measured yields. The difference between the theoretical and our experimental yields on photoproton reactions is explained by the isospin splitting of GDR, which is not accurately taken into account in the TALYS program, which leads to an underestimation of the production cross section of ^{105}Rh by almost an order of magnitude.

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CLUSTER STATES IN LIGHT NUCLEI

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The results of measuring the radii of some excited states of light nuclei are presented. A method based on the analysis the diffraction patterns of the cross-section (Modified diffraction model MDM) was proposed. We studied the inelastic α-scattering on ^{11}B, ^{12}C and ^{13}C with excitation of some states whose structure recently attracted a lot of attention from different theoretical investigations. The evidence that the famous Hoyle state (0^+, 7.65 MeV) in ^{12}C has the enhanced dimensions and is the head of a rotational band (besides the band based on the ground state) was obtained. The radius of the second 2^+ member state (E^* = 9.8 or 9.6 MeV) occurred to be similar to that of the Hoyle state (~3.0 fm). A 4^+ state was identified at E^*=13.75 MeV. The radii of the 8.86 MeV, $1/2^-$ state in ^{13}C and 8.56 MeV, $3/2^-$ state in ^{11}B occurred to be close to that of the Hoyle and these states can be considered as analogues of the latter. Comparison of the data with the predictions of such theoretical models as alpha condensation (AC) and antisymmetrized molecular dynamics (AMD) has been done. Though some of the predictions of AC (e.g., the probability of the L=0 component of alpha clusters in the Hoyle state) are close to the experiment most of the data disagree with them and one may speak only about rudimentary manifestation of the condensate effects.

Another question arises if analogues of the Hoyle state can be in other 4N systems. There are many predictions that some 0^+ states in ^{16}O have enlarged radii and can be considered as analogues of the Hoyle state. We applied MDM to data on inelastic scattering of α+^{16}O, E(α)=386 MeV with excitation of 0^+_3–0^+_6. We didn't observe any enhancement of radii of these states.

SEARCH FOR EXCITED STATES WITH ENHANCED RADII IN ^{12}B AND ^{12}N

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An experiment was done to search for states with a neutron halo in ^{12}B. The measurements were performed at Jyvaskyla University cyclotron using the Large Scattering Chamber (LSC). On base of ANC analysis of the obtained experimental data neutron halo was confirmed for 2^-, 1.67 MeV and 1^-, 2.62 MeV states. An unexpected result was received for the unbound 3^-, 3.39 MeV state. Its halo radius was found to be increased and equal to ~6.5 fm. This result can be considered as an evidence of the neutron halo in this state of ^{12}B, which would indicate to the first halo excited state with a nonzero orbital momentum of the last neutron. Also the large neutron rms radius ~5.6 fm was found for the 2.72 MeV 0^+ state.

There is reason to expect that the proton halo can exist in the nuclei of other members of the isobaric triplet ^{12}B-^{12}C-^{12}N. We can expect the formation of a proton halo in the states of ^{12}N (2^-, 1.19 MeV and 1^-, 1.80 MeV) nuclei. To check this prediction MDM analysis of existing (^{3}He, t) experimental data was done.

*E*0 TRANSITIONS IN EVEN-EVEN NUCLEI OF DYSPROSIUM WITH *A* = 156, 158, 160

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Experimental and theoretical justification of reliable existence of transitions with multipolarity *E*0 and their placement in decay schemes is sometimes insufficient and requires additional investigations [1–3].To this end, analysis was given to conversion electron intensity lines of *E*0 and *E*0+*E*2 transitions in the ^{156,158,160}Dy nuclei measured at different spectrometers (see Table), γ-ray spectra, and γ-γ coincidence spectra. Structures and probabilities of transitions are calculated for 0^+ states and compared with the experimental data.

Table. Relative intensities of electron conversion lines from E0- u E0+E2- transitions in ^{160}Dy, measured on different beta spectrometers.

Line	$\pi\sqrt{2}$ (1966) [3]	β-spectrograph, $2\pi\sqrt{2}$ (1969)[3]	UMB (1978) [3]	β-spectrograph (2006-2009)	Mini-orange, Si(Li) (2001-2009)
*K*672.3 *K*673.1	0.21±0.06	<0.1	0.25±0.04	0.34 0.62	0.27±0.03
*K*681.3 *K*682.3	1.0±0.2	0.9±0.2	1.20±0.05	0.24 0.90	1.20±0.10
*K*703.4		0.4±0.1		0.33	<0.033
*K*1262.8	1.1±0.2	1.05±0.10	1.09±0.10		1.1±0.1
*K*1271.0 *K*1271.9	0.9±0.1	0.93±0.10	0.81±0.10	0.24 1.06	0.9±0.1
*K*1280.0	0.5±0.1	0.45±0.05	0.36±0.04	0.53	0.40±0.04
*K*1456.7					<0.006
*K*1708.2				0.33	<0.01
*K*1952.3	0.15±0.03	0.16±0.03	0.15±0.02	0.15	0.15±0.02

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THE DECAY OF HIGH SPIN (9^+) STATES OF ^{156,158,160}Ho

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Some experimental results concerning to investigate the decay of the high spin isomers of odd-odd nuclei of the excited states of dysprosium's daughter nuclei have been discussed [1–10].

A beta-decay of the isomer ^{156m2}Ho in dysprosium daughter nuclei (2789 keV) neutron state and a rotational band of the ground state has been analyzed. The discharge of the state 2789 keV in the dysprosium nuclei has occurred through the strong forbidden by *K* number gamma transitions.

The intensity of the observed gamma-transitions, which discharge the 2789 keV state, has been estimated.

The decay of the isomer ^{158m2}Ho in the level 2528 кeV of the neighbor nuclei ^{158}Dy has been accompanied analogically by strong *K* prohibition, $\Delta K= 8$.

The experimental results, representing the investigations of the decay of the isomer ^{160m2}Ho on the level of strong deformed nuclei of ^{160}Dy, have not allowed making the analogy to the decay of the isomers ^{156,158m2}Ho.

We have discussed a comparison between experimental data and theoretical calculations' results, got in the frame of microscopic version of the model of interacting bosons (IBM1) [11].

The scientific work has been carry out by the support of Russian Fund of Basic Research RFBR.

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NEUTRON RADII OF Ca AND Zr ISOTOPES NEAR THE NEUTRON DRIP-LINE WITHIN THE DISPERSIVE OPTICAL MODEL

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Neutron single-particle characteristics, density distributions and neutron root-mean-square radii of Ca and Zr isotopes near the neutron drip-line were calculated within the dispersive optical model [1]. According to the DOM calculation, the root-mean-square radius $\langle r_n \rangle$ of the neutron density distribution demonstrates a very rapid growth for the Ca and Zr nuclei approaching to the neutron drip-line (see Fig. 1) and deviates sufficiently from the extrapolated linear dependence on relative neutron excess $\delta = (N–Z)/A$ at $\delta > 0.33$ for Ca isotopes and at $\delta > 0.18$ for Zr isotopes. Neutron $3s_{1/2}$ and $2d_{5/2}$ states in Ca isotopes and $3p$, $2f_{7/2}$ states in Zr isotopes create main contribution to halo. This result is in accordance with the predictions [2, 3] of the giant neutron halo in neutron-rich isotopes of Ca, Zr, which were obtained by relativistic continuum Hartree-Bogolyubov model and non-relativistic Skyrme Hartree-Fock-Bogolyubov model.

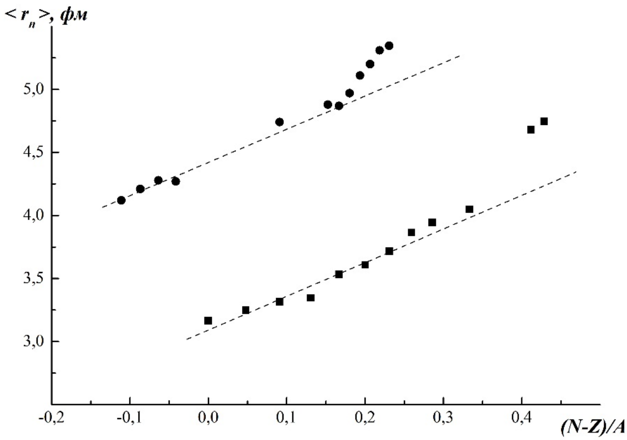

Fig. 1. Neutron root-mean-square radii $\langle r_n \rangle$ for Zr and Ca isotopes. Squares (Ca) and circles (Zr) – calculation by DOM, dashed lines – linear dependences drawn as a guide.

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MODULATION OF ANGULAR DISTRIBUTIONS OF SCATTERED ALPHA PARTICLES BY MULTICLUSTER NUCLEI

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In [1], for the first time, we explained the phenomenon of a significant excess of cross sections over Rutherford at small angles, which turned out to be a fragment of a simple diffraction pattern with oscillations $\Delta\theta_\alpha$ of a longer period than oscillations on the core-matrix $\Delta\theta_\alpha$ as a whole, that is, $\Delta\theta_\alpha > \Delta\theta_n$. This large period $\Delta\theta_\alpha$ turned out to be the first diffraction ring on intranuclear spatially isolated α-clusters. This explanation is reliable, since the existence of α-particle nuclear matter has been comprehensively investigated by us and, thus, proved earlier [2] on the basis of other experimental data.

In this work, a wide systematic of the modulation parameters of Fraunhofer oscillations on matrix nuclei from lithium to nickel with oscillations from the elastic scattering of incident α particles on intranuclear multicluster with masses from the proton to the α particle is carried out. Cluster widths, equivalent to the stats of multicluster, are taken from our work [3].

$$\sigma_{\mathrm{tot}} N_{\mathrm{tot}} = \sigma_0 N_0 + \sigma_1 N_1 + \ldots + \sigma_{\mathrm{n}} N_{\mathrm{n}}$$

For the cluster widths of nuclei-matrix are unknown, these parameters were found by describing the experimental angular distributions of the differential cross sections for elastic scattering using the method proposed in [1].

For expansion of the list of the detected multicluster, NNDC databases of experimental angular distributions of the differential cross sections for elastic scattering with doubly magic nuclei with ^{16}O as incident particle were used.

Such incident particles made it possible to find multi-clusters in nuclei with masses from $A = 4$ to $A = 16$.

Thus, the phenomenon of modulation has been extended by us in this work for all the stat widths of all multicluster, which raises new questions to experimental methods increasing the accuracy of measuring the maximums of diffraction oscillations.

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STRUCTURE OF β-DECAY STRENGTH FUNCTION $S_\beta(E)$ IN HALO NUCLEI

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The strength function $S_\beta(E)$ governs [1, 2] the nuclear energy distribution of elementary charge-exchange excitations and their combinations like proton particle (πp)–neutron hole (νh) coupled into a momentum I^π: $[\pi p \otimes \nu h]_I^\pi$ and neutron particle (νp)–proton hole (πh) coupled into a momentum I^π : $[\nu p \otimes \pi h)]_I^\pi$. The strength function of Fermi-type β-transitions takes into account excitations $[\pi p \otimes \nu h]_0^+$ or $[\nu p \otimes \pi h]_0^+$. Since isospin is a quite good quantum number, the strength of the Fermi-type transitions is concentrated in the region of the isobar-analogue resonance (IAR). The strength function for β-transitions of the Gamow-Teller (GT) type describes excitations $[\pi p \otimes \nu h]_1^+$ or $[\nu p \otimes \pi h]_1^+$.When the nuclear parent state has the two-neutron Borromean halo structure, than IAR and configuration states (CSs) can simultaneously have nn, np Borromean halo components in their wave functions[3–5].

In this work, the structure of resonances in the GT β-decay strength function $S_\beta(E)$ for halo nuclei is analysed. It is shown that when the parent nucleus has *nn* Borromean halo structure, than resonances in the GT β-decay strength function $S_\beta(E)$ of halo nuclei, may have np tango halo [3–5] structure and mixed np tango + nn Borromean halo structure. Since the operators of GT β-decay and *M*1 γ-decay have no spatial components, GT β-transitions and *M*1 γ-transitions between states with similar spatial shapes are favored. Data of ^{6}He (Borromean nn halo) ground state (g.s., I^π=0$^+$) GT β-decay and *M*1 gamma decay of its IAR (Borromean np halo, resonans in ^{6}Li, E=3.56 MeV, I^π=0$^+$) are discussed. A rather large value of the transition strengths: $B(M1,\sigma)$ = 8.2 W.u. for *M*1 γ-decay from IAR and $B(\mathrm{GT}) \approx 5g_A^2/4\pi$ (Σ(sum rule) = $6g_A^2/4\pi$) for GT β^- decay to the ^{6}Li g.s. (I^π=1$^+$), complies the presence of an np tango halo in ^{6}Li g.s.

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COLLECTIVE STATES IN ^{156}Dy

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Collective states in the ^{156}Dy nucleus were described within the IBM1 phenomenology, when the Hamiltonian parameters and the effective charges of the $E2$-transition operator are determined such as to obtain the best description of the characteristics of several collective bands. The difference between experimental and theoretical energy states of the ground band for $I \leq 8$ are smaller 7 keV and for $I = 10^+$, 12^+, 14^+, 16^+, 18^+ according smaller 24, 75, 120, 245, and 355 keV. The increasing difference between the phenomenological and experimental energies beginning with spin $I = 10^+$ can be caused by both the influence of the high-spin quasiparticle pairs and by possible influence of the interaction members $(d^+d^+d^+)^{(\lambda)}\cdot(ddd)^{(\lambda)}$ which are absent in the standard IBM1 Hamiltonian. Experimental energies of the states of the beta and gamma bands with an identical spins are rather close in values, which cannot be quantitatively reproduced by calculations. In addition, the description of the beta band is lower in quality than the description of the gamma band. This may point to a pair-vibrational character of this band.

Another way to consider properties of collective states involves microscopic calculations of the IBM parameters using the spherical mean field. A special modified quasiparticle random phase method is implemented, which allows for the fact that there is a number of quadrupole phonons in each collective state. The problem of mutliphonon states is solved by going over from phonons to ideal bosons. Noncollective quadrupole phonons and pairs with spin $J^\pi \leq 6^+$ are considered using renormalizations of the parameters of the Hamiltonian and $E2$-transition operators in terms of quadrupole d-bosons. Interaction of multiphonon states with states including high-spin two-quasiparticle pairs with moments $J = 8^+$, 10^+ are additionally considered [1]. This gives a satisfactory description for the states of the ground-state band up to the spin $I \leq 16$. The gamma band can also be described by slightly varying the spin-orbit interaction constant of the mean field. In the ground-state band, states with spin $I \leq 10^+$ are exhausted by D and others phonons with $J \leq 6$ that determine renormalizations of boson parameters of operators. For the state with $I = 12^+$ the component with the pair $J = 10^+$ is about a half of the overall normalization. This allows having smooth variation in $B(E2)$ for all transitions considered in the ground-state band.

Among the states in ^{156}Dy there is 8^+ state populated by the β^+ decay of the isomeric 9^+ state in ^{156}Ho. Based on the single-particle states and the fact of the decay, one can assume that the 8^+ state with the energy of 2788 keV is determined by either the $(h_{9/2})^{2(8+)}$ or the $(f_{7/2}h_{9/2})^{(8+)}$ configurations. In this energy region there are more than ten states with this spin. Beta decay separates one of them [2]. Experimental value $B(E2;\, 8_q \to 10_1)/B(E2;\, 8_q \to 6_1) = 8.9$. If 8_q is determined by the $(h_{9/2})^{2(8+)}$ neutron configuration, this ratio is 3 and if the configuration is $(f_{7/2}h_{9/2})^{(8+)}$, the ratio will be 0.4.

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COLLECTIVE STATES IN ^{158}Dy

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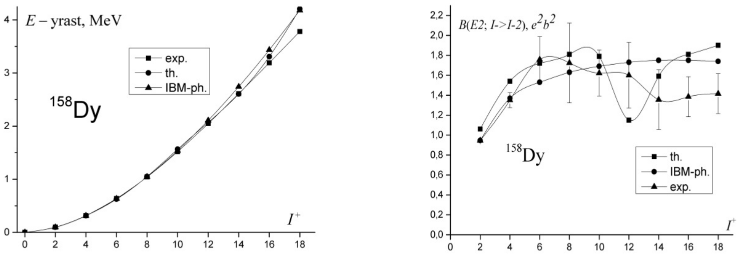
Properties of collective states in ^{158}Dy were studied in the same way as in this book for ^{156}Dy. Since the phenomenological analysis within the IBM1 does not define a unique region of values for parameters of the IBM1 Hamiltonian, especially when beta band states are ignored, so an attempt was made to find those values of the parameters which fall within the region of the values obtained from the microscopic calculation. This allows the states of the ground-state and gamma bands to be reproduced. If the IBM1 Hamiltonian has the form

$$H_{\mathrm{IBM}} = \varepsilon_{\mathrm{d}} d^+ \cdot d + \left(k_1 d^+ \cdot d^+ ss + k_2 (d^+ d^+)^{(2)} \cdot ds + \mathrm{H.c.}\right) + 1/2 \sum\nolimits_L C_L (d^+ d^+)^{(\mathrm{L})} \cdot (dd)^{(\mathrm{L})}$$

the microscopic values of the parameters ε_{d}, k_1, k_2, C_0, C_2, C_4 at the total number of bosons $\Omega = 26$ turn out to be –1.107, –0.0728, 0.0119, 0.205, 0.086, and 0.1530. The phenomenological parameters at the same total number of bosons are –1.133, –0.0566, 0.0065, 0.183, 0.043, and 0.055 respectively. The respective energies of the ground state with respect to the bosonless state are –21 and –30 MeV. The coherent state energy minimum occurs at the deformation parameter $\beta \approx 0.28$. If smaller values of the quadrupole particle–hole forces are used (no more than 10%), the deformation parameter remains unchanged while the depth of the well decreases down to 10 MeV, but it is only in the first case given above that the absolute values of $B(E2)$ are correctly reproduced without introduction of effective charges.



The figures show the energies of the yrast band and the values of $B(E2)$ inside it.

A noticeable difference between the theoretical and the experimental energy of the 18^+ state may already indicate that there is already influence of four-quasiparticle states.

In the nucleus under consideration, as in ^{156}Dy, a strongly noncollecitve 8^+ state with the energy of 2.528 MeV is observed. Experimental observation of these states in ^{156,158}Dy is due to the presence of high-spin (9^+) isomers in ^{156,158}Ho and their decay to the levels of the dysprosium daughter nucleus. For states 9^+ in ^{156,158}Ho the only observed channel of decay are β^+-process on 8^+ states in ^{156,158}Dy. This is the result of high degree of forbiddenness on multipolarity for γ-transitions inside ^{156,158}Dy isotopes [1].

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CLUSTERIZATION AND CRYSTALLIZATION OF NUCLEI

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The review gives the main aspects of the fundamentally new emerging nuclear physics.

Section 1 discusses theoretical and experimental facts about the clustering of nuclei and examines experimental evidence of their actual existence. A method for measuring and identifying each type of cluster in one experiment and in one mass spectrum is described.

Section 2 generalizes the sum of the experimental facts in favor of the solid model of the nucleus and the ordering of its structure into a quasicrystalline lattice. Systematics of the geometric parameters of the nuclei - radii, surface diffusion and shape deformation is given throughout the «Valley of Stability». It is shown that superdense nuclei whose density significantly exceed the mean (normal) density n_0 = 0.147 fm exist. These are nuclei from ^{4}He to ^{32}S, while the maximum density (superdensity) is demonstrated by the ^{4}He nucleus (α-particle). This suggests two “bricks” of nuclear composition – nucleons and α-particles, and the densest spherical packings in a binary nuclear system: in fact, the ratio of their radii is theoretically equal to 0.4142. And the ratio of the radii of nucleons and α-particles is exactly equal to

$$\frac{r_{\mathrm{p}}}{r_{\alpha}} = \frac{0.7\ \mathrm{fm}}{1.68\ \mathrm{fm}} = 0.417\,.$$

And if we follow this theory, then the «Island of stability», we propose to search not at Z = 114, but at Z = 128.

Section 3 gives facts and generalizations in favor of constructing a new nuclear theory in the basis of the topology of a curvilinear non-Euclidean space. Inside the nucleus volume and in the near-nuclear space, this is a Riemannian space with a geodesic in the form of an ellipse with positive curvature κ > 0. The closed Riemannian space in the microworld of nuclei is the area inside the «Valley of Stability». On the edges of this valley the Riemannian space opens into a flat Euclidean space with zero curvature κ = 0. Outside the nucleus, the Riemannian space at the Fermi boundary is rectified. Then the zero curvature undergoes a discontinuity and goes over into the Lobachevsky space with negative curvature κ < 0, and the corresponding instability of the nuclear structure, which serves as the fundamental cause of radioactivity.

SEARCH FOR LIGHT MULTINEUTRONS IN FISSION OF ^{238}U INDUCED BY NEUTRONS FROM THE IR-8 REACTOR

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A search for the light nuclear-stable clusters of neutrons among products of ^{238}U fission which was induced by the fast neutrons from the IR-8 reactor has been performed at National Research Center "Kurchatov Institute". Intensity of neutrons ($E_n > 0.8$ MeV) was ~(2÷3)×10^8 cm^{-2}s^{-1}. Two irradiations with samples of chemically pure ^{27}Al (2.5 g) and enriched ^{24}Mg (99.9%, 1.7 g) were conducted. The activation time with ^{27}Al and ^{24}Mg samples was about 20 and 66 hours, respectively. The target of natural uranium had a thickness of 1.4 mm. The samples were placed at 5 cm from center of the target at the angle of 130° relative to the beam direction.

In first experiment the detection of ^{x}n was carried out by using the reaction ^{27}Al + ^{x}n → ^{28}Mg + p (x–2)n reaction. Identification of neutron nuclei was done by the characteristic gamma-lines with the energies of E = 1342 и 1779 keV emitted in the beta-decay chain: ^{28}Mg → ^{28}Al → ^{28}Si. Gamma-spectra were measured after cleaning of the irradiated samples from ^{24}Na isotope produced in the ^{27}Al(n, α) background reaction. The cleaning was made by the method of thermal diffusion in an electrostatic field.

In second experiment the reaction of four-neutron transfer ^{24}Mg(^{x}n, (x–4)n)^{28}Mg was used with the identification of the same ^{28}Mg isotope. In this case the presence of ^{24}Na is also found (from the (n, p) reaction) but with much smaller amount that allowed to measure gamma-spectra without cleaning.

Finally, in both experiments there are no characteristic gamma-lines that could be attribute to the production of ^{28}Mg isotope were observed. The additional experiments to search for ^{x}n using other reactors with more intense neutron fluxes are planned.

EVOLUTION OF THE SINGLE-PARTICLE STRUCTURE OF NEUTRON-RICH ISOTONES WITH *N* = 20 WITHIN THE DISPERSIVE OPTICAL MODEL

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The evolution of single-particle characteristics of isotones with $N = 20$ approaching to the neutron drip-line is calculated within the dispersive optical model [1]. In particular, the prerequisites to form the island of inversion at $Z \leq 12$ which arise within the spherical version of the model were investigated. According to the calculation, the $N = 20$ gap rapidly decreases, while the $N = 16$ gap increases (see Fig. 1) for the isotones approaching to the neutron drip-line. The neutron state $2p_{3/2}$ becomes the first predominantly unoccupied state at $Z < 12$. Thus, the particle-hole gap between $1d_{3/2}$ state with the spin $j = 3/2$ below the Fermi energy E_F and the $2p_{3/2}$ state with the same spin $j = 3/2$ above E_F is formed. Each of the states, being fully occupied, can contain 4 neutrons. This result is in agreement with the significant increase of the contribution of $4p4h$ excitations to the ground state of ^{32}Mg [2, 3], which determines its position on the shore of the island of inversion.

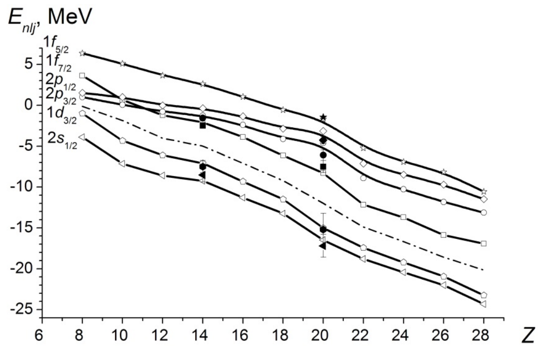

Fig. 1. Neutron single-particle energies E_{nlj} of N = 20 isotones calculated by DOM (open symbols connected by the solid lines) in comparison with the experimental data (solid symbols), dashed-dotted line – the Fermi energy.

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INVESTIGATION OF CLUSTER CONFIGURATIONS OF NUCLEI FROM ^{11}B TO ^{209}Bi ON α-PARTICLES BEAMS

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The discovery of two new kinematic methods of detection and investigation of intranuclear multicluster [1] with accurate registration of multicluster kinematics («kintracks») was surprisingly universal, unambiguous and reliable. The only limitations of the method are: 1) the probing particle must be twice magical so that its structure does not appear to be a perturbing factor for the structure of multicluster nuclei; 2) the path of the probing particle in the probed nuclear matter (in the nucleus-matrix) must be comparable or larger than the diameter of the nucleus -matrix, that is, the energy of the probing particle must be appropriately selected.

The experiments were performed on beam of 29 MeV α-particles at ^{11}B, ^{13}C, ^{24}Mg, ^{25}Mg, ^{59}Co, ^{120}Sn, ^{197}Au, and ^{209}Bi nuclei in the angular range from 10° to 89° in laboratory system. The aim of the measurements was to search for light multicluster with mass numbers from 1 to 4: p, d, ^{3}He, α in the indicated nuclei. In this case, we assume a nonzero probability of the existence of such multiclusters inside the volume of the investigated nuclei with the indicated mass numbers, which do not exist in the free state, but in the nucleus volume, in connection with the Heisenberg uncertainty relation, they have a finite probability for existence. To achieve this goal, two tasks were accomplished: 1) find the effect of «dissolution» of multiclusters with increasing mass number; 2) find the effect of «raising» of α-clusters that survived the dissolution process on the surface of the nucleus with increasing mass number.

As a result of systematic experimental studies, both effects have been found - the corresponding cluster widths have a trend toward a decrease in the transition to heavy nuclei. As for such «solid nuts» as nucleons and α-clusters, their survival in a medium with giant nuclear forces tearing loose multicluster into pieces means their high binding energy contributes to their survival. But, nevertheless, alpha-clusters are raised up to the surface by nuclear forces, giving rise to the phenomenon of alpha-radioactivity. The mass spectra of multiclusters are studied. The cluster widths θ_n^2 for them are introduced by us in the $N_0 = N_1 + N_2 + \cdots . + N_n$; $1 = \frac{N_1}{N_0} + \frac{N_2}{N_0} + \cdots + \frac{N_n}{N_0} = \theta_1^2 + \theta_2^2 + \cdots + \theta_{n1}^2$ form. It is shown that cluster widths decrease with increasing mass number. Effective numbers of clusters are found across the whole range of mass numbers. Both the widths and effective numbers confirmed the existence of the above new nuclear effects with exotic nuclei and clusters.

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MODERNIZATION OF THE SCATTERING CAMERA ON THE U-400 BEAM FOR PRECISION MEASUREMENTS OF HEAVY MULTICLUSTERS

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In experimental studies of multicluster parameters in nuclei, specific, rather stringent, requirements are imposed on the scattering chamber. First of all, this concerns the total angular resolution of the spectrometer of scattered particles, which consists of two components. The first component is the angular spread of the beam $\Delta\theta_k$, determined by the passive input collimator of the scattering chamber. It is regulated by the diameter of the input cutting diaphragm d_1, the diameter of the output diaphragm d_2 and the distance between them (the base of the input collimator) L. Then the angular resolution of the input collimator will be determined by the formula $\Delta\vartheta_k = 2\text{arctg}\frac{d_1+d_2}{2L}$.

The second component of the total angular resolution of the spectrometer is the geometric system «beam spot on the target (d_m) + input diaphragm of the particle detector (d_d)» and the distance between them (the base of the «target-detector» system) L_{md}. Especially note that it is the beam spot on the target that serves as the "input cutting diaphragm" for the imaginary (virtual) «collimator» of the particle detector. Then the angular resolution of the «target-detector» system will be determined by the formula $\Delta\vartheta_{md} = 2\text{arctg}\frac{d_m+d_d}{2L_{md}}$.

A very important parameter in the attempt to achieve the minimum angular resolution of the spectrometer $\Delta\vartheta_{sp}$ is the distance from the output cutting diaphragm of the input passive collimator to the nuclear target l. Note that this parameter, as a rule, is often overlooked by many researchers. The formula for calculating the beam spot on the target has the form $d_m = d_2 + (d_1 + d_2)\frac{l}{L}$.

With the first measurements of Wulf-Bragg diffraction on quasicrystalline nuclei in the zinc region, we apparently used such a stiff collimation of the beam and the entire geometry of the experiment.

It should be noted that in the planning of experiments with good angular resolution, the use of slotted, square, rectangular and other forms of collimators is absolutely unacceptable. In all these cases, the angular resolution of the spectrometer is completely determined by the diagonal sizes of all these geometric figures.

STRUCTURE AND TOTAL STRENGTH OF THE MAGNETIC DIPOLE RESONANCE ON EXCITED STATES IN *sd* SHELL NUCLEI

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The γ-decay of resonance-like structures (RLS) observed in the reaction of radiation capture of protons by ^{22}Ne, ^{26}Mg, ^{30}Si, ^{34}S, ^{36}S, and ^{38}Ar nuclei in the energy range of accelerated protons of 0.8–3.0 MeV is studied. The measurements were performed on the ESU-5 accelerator at the NSC KIPT. The distribution of magnetic dipole γ transitions on the ground and excited states is obtained. The obtained discrete distributions of the *M*1 transitions have a resonant character. The magnetic dipole resonance (MDR) on the ground and excited states of ^{23}Na, ^{27}Al, ^{31}P, ^{35}Cl, ^{37}Cl, ^{39}K nuclei is identified. The RLS observed by us have a complex structure, i.e. consist of states that belong to both the *M*1 resonance on the ground state and to the *M*1 resonance built on the excited states. The position of the center of gravity (CG) and the value of the total strength of the MDR on the ground and excited states in these nuclei are determined. It follows from the obtained data that the position of the MDR CG on the ground state in odd-odd nuclei differs from the position of the MDR CG in even-even nuclei by 3 MeV. At the same time, of the MDR CG in odd nuclei with a filled $d_{5/2}$ sub-shell (^{31}P, $^{35, 37}$Cl, ^{39}K) is 3 MeV higher than of the MDR CG in nuclei with an unfilled $d_{5/2}$ sub-shell (^{23}Na, ^{25}Mg, ^{27}Al) . The position of the center of gravity of the MDR on excited states for odd nuclei coincides with that predicted by the Brink-Axel hypothesis for nuclei at the beginning of the sub-shell (^{23}Na – $d_{5/2}$ sub-shell, ^{31}P – $d_{3/2}$ sub-shell) and differs by 3 MeV for nuclei with an almost filled sub-shell (^{27}Al – $d_{5/2}$ sub-shell; ^{39}K – $d_{3/2}$ sub-shell). This may be due to the influence of the pairing energy of nucleons on the properties of MDR in the nuclei of the *sd* shell. The behavior of the total MDR strength on the ground state for the odd nuclei of the *sd* shell corresponds to that obtained from the Kurath sum rule in the framework of the one-particle shell model [1]. At the same time, the total strength of the MDR on excited states does not correspond to that obtained from the Kurath sum rule. This may be due to an increase in the role of collective motion in the structure of excited states.

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A NEW SCATTERING CHAMBER FOR CONDUCTING PRECISION EXPERIMENTS ON THE HEAVY-ION REACTION CROSS SECTIONS AT THE ACCELERATOR DC-60 (ASTANA, KAZAKHSTAN) AT LOW ENERGIES

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Within the framework of the long-term program of cooperation between JINR, ENU and Institute of Nuclear Physics (INP), joint experiments connected with the peculiarities of the interaction of lithium nuclei $^{6-9,11}$Li at energies near the Coulomb barrier will be conducted on the U-400M cyclotron of G.N. Flerov Nuclear Reaction Laboratory (FLNR JINR) and on the DC-60 accelerator (Astana) of the INP. To obtain new experimental information on the properties of weakly bound (cluster and exotic) lithium nuclei (the entire chain of lithium isotopes) and their manifestation in interaction with other nuclei, the features of the angular distributions of elastic and inelastic scattering cross sections, the energy dependences of the total reaction cross sections $\sigma_R(E)$ and cross sections of individual dominant reaction channels; the corresponding reaction mechanisms in the previously unexplored region of energy will be studied.

Experiments in Astana (Kazakhstan) are supposed to be carried out at the DC-60 using a new scattering chamber and corresponding detector systems and nuclear electronics, which was manufactured at the FLNR JINR. The new dispersion chamber for the DC-60 is a completely new modern installation, which includes a new electronic system for collecting and processing experimental information FASTER.

Control experiments using the new camera will be conducted on beams ^{6,9,11}Li at the FLNR JINR and on ^{10}B, ^{10}C nuclei – on the DC-60. These nuclei (^{6,7,9}Li) have a weakly bound cluster structure, and the ^{11}Li nucleus is an exotic nucleus with a very low binding energy (E_{bind} = 0.3 MeV). In such experiments, we are expected to detect the features of their manifestation in nuclear reactions near the Coulomb barrier: subbarrier fusion, an increase in the cross section for cluster transfer reactions, features in the angular distributions of elastic and inelastic scattering, and features in $\sigma_R(E)$. The obtained information is of great importance for fundamental nuclear physics and in other fields of science, for example, for describing the scenario of nucleosynthesis in astrophysics.

OUTLIERS IN THE SEQUENCES OF COUNTS OF RADIATION FLOW PARTICLES

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Stationary sequence of counts $K(\Delta t)$ of the number of particles emitted by a long-lived radioisotope source with $T_{1/2} > 1$ year over intervals $\Delta t \ll T_{1/2}$, as is known, conforms with the stationary Poisson time series with parameter $\overline{K} = \nu\Delta t,$ at $\nu = \text{const}$.

According to work [1], during beta-decay of long-lived isotopes ^{60}Co, ^{90}Sr, ^{137}Cs with duration of continuous measurements $T < T_{1/2}$, in sequences $K(\Delta t)$ periodically appear, including 24-hour period, significant outliers – extreme values $K(\Delta t) > \overline{K}(\Delta t)$.

In our work, the statistical analysis of the data obtained when measuring series $K(\Delta t)$ for alpha-radiation ^{238}Pu by the method of work [2] with $\overline{K}(\Delta t) = 1 \div 4.6;\ \nu = 23\ \text{s}^{-1};\ \Delta t = 0.05;\ 0.1;\ 0.2\ \text{s}$ and $T \le 820$ hour, has shown the following. 1) Distribution of values $K(H, \Delta t) > H = nS$ and $H < K(H, \Delta t) \le H + 1$ at $H = nS'$, $n = 3,\ 4,\ 5$, where $S^2(K(\Delta t))$ is a sampling variance, $K(\Delta t)$ conforms with the Poisson distribution. 2) Distribution of intervals $r(K(H, \Delta t))$ between sequential outliers conforms with the geometric and exponential distributions. Average values $\overline{r}(K(H, \Delta t))$ are not divisible by the 24-hour period within the limits of confidence intervals with the Student factor $t = 2$. The value $\overline{r}(K(\Delta t))$ deterministically depends on H and $\overline{K} = \nu\Delta t,$. Varying H, ν and Δt, we can fit their values so that $\overline{r}(K(H, \Delta t)) \sim l \cdot 24$, $l = 1, 2, \ldots$. However, no periodic formation of outliers $K(H, \Delta t)$ occurs. The autocorrelation and cross-correlation analysis of sequences $K(\Delta t)$ in the time and spectral representations with the Parzen and Bartlett windows also revealed no significant periodic components, including a component with 24 hours.

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EXPERIMENTAL INVESTIGATIONS OF NUCLEAR REACTIONS MECHANISMS

INVESTIGATIONS OF THE NUCLEAR REACTION EXCITATION FUNCTIONS WITH MEDICAL RADIONUCLIDES WHICH FORMED IN THE EXIT CHANNELS

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Today in low energy nuclear reaction physics one of the most important tasks is the studying of the reactions leading to the formation of radionuclides used in medicine for the effective earlier diagnosis of the different oncological diseases. These radionuclides are also used for the precise targeted therapy of the various localized tumor. The novel therapeutic radionuclides (in particular Auger electron emitters), offer the advantages of short-range biological effectiveness and high cytotoxicity, which is suitable for the targeted therapy [1]. In combination with the radionuclides for patient-specific Single-photon emission computed tomography (SPECT) it provides an excellent treatment results with minimum side effects, merging modern imaging methods and radiotherapy («theranostics» a combination of therapy and diagnostics).

In present work the experimental and theoretical studies of (p,n) reactions excitation function with ^{117}Sb and ^{119}Sb radionuclides formation in the exit channels have been carried out. The using staked foils method with new targets, the different monitor reactions for the beam characteristics (beam energy, beam current) determinations were investigated.

For the proton energy range of the low energy cyclotrons (used for the production of the radionuclides for medical application) the detailed studies of an excitation function maximum of the ^{119}Sn(p,n)^{119}Sb reaction have been done. Also for the first time the cross-section data were observed for the ^{117}Sn(p,n)^{117}Sb reaction at the proton energy range from 10 MeV to 14 MeV.

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RADIAL FLOW IN THE INTERACTION OF RELATIVISTIC DEUTERONS WITH A GOLD TARGET

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The kinetic energy spectra of intermediate mass fragments have been studied for 4.4 GeV d+Au collisions at the Dubna Nuclotron with the FASA [1] 4π detector array.

Experimental kinetic energy spectra were compared to that obtained by the multi-body Coulomb trajectory calculations with the various values of radial flow. The analysis has been done on an event by event basis. The multibody Coulomb trajectory calculations of all charged particles have been performed starting with the initial break-up conditions given by the combined model INC [2] + SMM [3]. A comparison of the experimental and calculated kinetic energy spectra of carbon fragments is presented in Fig.1.

It was found good agreement of measured and calculated kinetic energy spectra including a radial flow. The research was supported by Grant No. 15-2-02745 from Russian Foundation for Basic Research.

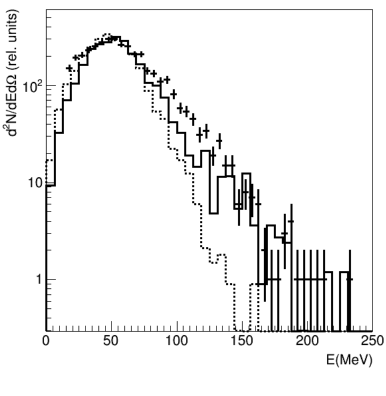

Fig. 1. The kinetic energy spectra of carbon fragments (Θ=87°) obtained by the interaction of deuterons 4.4 GeV with a gold target. Points – experimental data. Solid line – INC+SMM calculations with radial flow β=0.12c. Dotted line corresponds to INC+SMM calculations without radial flow.

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THREE-BODY CORRELATIONS IN ^{6}Be POPULATED IN (p,n) REACTION

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The nuclear driplines are defined by instability with respect to particle emission, and therefore the entire spectra of the systems beyond the driplines are continuous. The first emission threshold in the light even systems is often the threshold for two-neutron or two-proton emission, and therefore one has to deal with three-body continuum. Such continuum provides rich information about nuclear structure of ground state and continuum excitations, which is, however, often tightly intertwined with contributions of reaction mechanism.

The 47 *A*·MeV ^{6}Li beam was produced by the cyclotron U-400M and injected into ACCULINNA facility [1]. The ^{6}Be continuum states were populated in the charge-exchange reaction ^{1}H(^{6}Li,^{6}Be)n collecting very high statistics data (~$5\cdot10^6$ events) on the three-body α+p+p coincidences. The first results of the experiment studying the α+p+p correlations were published in Ref. [2]. The paper was focused on the proof that the observed ^{6}Be excitation spectrum above ~3 MeV is dominated by the novel phenomenon – isovector breed of the soft dipole model. The correlations in the decay of ^{6}Be states with excitation energy below ~3 MeV, where the data are dominated by the contributions of the known and well-understood 0^+ and 2^+ states of ^{6}Be, are presented.

A general quantum-mechanical formal issue and important practical task of data interpretation is the extraction of the most complete quantum-mechanical information from the accessible observables. For the majority of classes of experimental data, extraction of complete quantum-mechanical information is not possible. For certain classes of reactions the most complete quantum-mechanical information which can be extracted is contained in the density matrix.

We demonstrate that basing on the known level scheme it is possible to extract the maximal possible quantum mechanical information about reaction mechanism from the three-body correlations. It is demonstrated how the high-statistics few-body correlation data can be used to extract detailed information on the reaction mechanism. The suggested method of analysis allows for identification of fine effects and it may be regarded as a general tool for different tasks on radioactive beams.

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ANGULAR CORRELATIONS IN THE 14.1 MeV NEUTRONS INELASTIC SCATTERING ON Al

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The angular distributions of the γ-quanta from ^{27}Al(n, n′γ) reaction were measured using the tagged neutrons method and the TANGRA setup of JINR FLNP [1, 2]. The neutron generator ING-27 was used as a 14.1 MeV neutron source. The γ-quanta, emitted in the neutron inelastic scattering (INS), were registered by a system of 22 NaI(Tl) scintillator detectors, placed around the sample with 15° step. For protection of the γ-detectors from ING-27 neutrons, a compact iron shielding was used. The background radiation induced events were drastically reduced by "tagging" the neutrons and using the Time-of-Flight (ToF) method. This technique was successfully tested on ^{12}C [3].

For quantitative description of the γ-quanta emission angular distribution, an anisotropy parameter $W(\theta)$ is introduced and defined as a "normalized" differential cross-section: $W(\theta) = 1 + \sum_{i=2}^{2J} a_i P_i(\cos\theta)$ where J is a gamma-transition multipolarity, $P_i(\cos\theta)$ are Legendre polynomials.

There is some information on ^{27}Al(n, n′γ) reaction with ~14 MeV neutrons [4], but there are not angular distribution data published even in some databases [5]. We observed five γ-transitions in ^{27}Al and determined their $W(\theta)$ (see Tab. 1). In this experiment the anisotropy parameters obtained were found to be quite similar for all observed transitions.

Table 1. Legendre coefficients for angular distributions of γ-transitions in ^{27}Al*.

E_γ, MeV (multipolarity)	1.01 ($M1+E2$)	1.72 ($M1+E2$)	2.21 ($M1+E2$)	3.00 ($E2$)
a_2	0.22 ± 0.02	0.30 ± 0.01	0.30 ± 0.03	0.35 ± 0.03
a_4				0.06 ± 0.04

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SYSTEMATICS OF NEPTUNIUM AND PLUTONIUM TRACER CROSS SECTIONS IN THE p AND ^{3}He INDUCED REACTIONS

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The proton and ^{3}He induced reactions with ^{235,236,238}U and ^{237}Np are promising tool for production of neutron-deficient heavy nuclides which are particularly great of interest as tracers in the environmental studies. The excitation functions for ^{234,236,237}Pu and ^{234,235,236m}Np nuclides have been earlier obtained [1–6] (listed below in the Table).

Target	Reactions	Energies, MeV
^{235}U	^{235}U(p,γ) ^{236m}Np, ^{235}U(p,*x*n) $^{236–x}$Np *x*=1, 2	5 – 17.5
	^{235}U(^{3}He,*x*n)$^{238–x}$Pu *x*=1,2,4 ^{235}U(^{3}He,p*x*n)$^{237–x}$Np *x*=1–3	20 – 42.9
^{236}U	^{236}U(p,*x*n) $^{237–x}$Np *x*=1–3	6 – 40
	^{236}U(^{3}He,*x*n)$^{239–x}$Pu *x*=2,3,5 ^{236}U(^{3}He,p*x*n)$^{238–x}$Np *x*=2–4	20 – 60
^{238}U	^{238}U(p,*x*n) $^{239–x}$Np *x*=1,3	2 – 30
^{237}Np	^{237}Np(p,*x*n) $^{238–x}$Pu *x*=1,2,4; ^{237}Np(p,pn) ^{236m}Np	5 – 40
	^{237}Np(^{3}He,p*x*n)$^{239–x}$Pu *x*=1–3,5 ^{237}Np (^{3}He,α+2p2n)^{236m}Np	20 – 60

The experimental data were analyzed in the framework of the theoretical model with inclusion pre-equilibrium processes and the nuclear friction in fission channel [6, 7]. The direct reaction contributions were also estimated.

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FISSION MODES IN PHOTOFISSION OF ^{238}U BELOW 20 MeV

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The photofission of ^{238}U at the excitation energy range of the fissioning nucleus up to 20 MeV is studied. Gamma-activation analysis was used to measure the independent and cumulative yields of fission fragments after the release of fast neutrons. The experiment was performed on a bremsstrahlung gamma-ray beam of the RTM-55 electron accelerator with the upper limit of spectrum 55.6 MeV. The behavior of the symmetrical and asymmetric fission modes of $^{238}U(\gamma,f)$ and $^{235}U(n,f)$ depending on the average excitation energy of the fissioning nucleus is compared on the basis of these data and data from other experiments. An analysis of the obtained data shows that the contribution of the mode responsible for the symmetric fission of the fragments increases approximately by a factor of 10 with an increase of the ^{238}U excitation energy from 9 to 20 MeV. The contribution of the asymmetric mode STI decreases approximately by a factor of 2 in this energy range. The contribution of the asymmetric mode STII slightly increases in the region of the excitation energies of the nucleus up to 20 MeV. The work was supported by a grant from the President of the Russian Federation (MK-2693.2017.2).

INVESTIGATIONS OF ^{15}N IONS BY ^{16}O AT THE ENERGIES 1.25 AND 1.75 MeV/*A*

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The study of the elastic scattering and transfer reactions for heavy projectiles at energies close to the Coulomb barrier is very interested to determinate the real values of optical potentials of heavy ion interactions [1] for astrophysical applications.

The angular distributions of the ^{16}O + ^{15}N elastic scattering were measured at the energies E = 1.25 and 1.75MeV/*A*. The beam of ^{15}N was focused on the target Al_2O_3 with thickness 30 μg/cm^2 located in the center of the scattering chamber NEC on cyclotron DC-60 (INP, Astana). In our experiment, the detection system was equipped with ΔE-E telescope consisting of thick silicon detector (E) with thickness 200 μm and thin silicon detector (ΔE) with thickness 8 μm.

Optimal parameters of heavy ions interactions were installed in frame of optical model of nucleus, from analysis of the measured differential cross section of the elastic scattering ^{15}N ions on nuclei ^{16}O [2]. The data at backward angles showed a remarkable increase of the differential cross section due to the contribution of p-transfer. The experimental data were analyzed within the framework of OM to reproduce the cross sections at forward hemisphere (pure elastic scattering) and DWBA method to reproduce the data at backward hemisphere (elastic transfer) [3].

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TWO VARIANTS OF A MATRIX DETECTOR FOR DETECTING TWO COINCIDENT PROTONS IN THE d + d → p + p + n + n REACTION: SIMULATION OF THE EXPERIMENT, SELECTION OF SETUP PARAMETERS, TESTING OF PROTOTYPES

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At the present stage of nuclear physics development it is important to study effects of charge symmetry breaking (CSB) of nuclear forces. A quantitative estimation of the CSB effect can be obtained, for example, from an analysis of the experimental data on the d + d → p + p + n + n reaction. The data analyzed are energies of singlet virtual nn- and pp-states of the two-nucleon system E^s_{nn} and E^s_{pp} [1].

To determine the energy of the singlet pp-state in d + d → p + p + n + n reaction it is necessary to measure the energies and emission angles of the two protons in coincidence with the neutron. A charged particle telescope will be used to register the protons. This telescope consists of a ΔE-detector and a matrix E-detector. We present two versions of the E-detector. These variants are rather different. Due to the different construction they register different regions of the solid angle of proton emission (central and peripheral). And they also have different energy resolution.

The first experimental results (spectra of protons formed as a result of a quasi-bound pp-state decay) and their comparison with the results of kinematic simulation of this reaction are presented in the report. The kinematic simulation of reaction d + d → p + p + n + n is described in [2].

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A MEASUREMENT OF NEUTRON SPECTRUM OF W-Be SOURCE DETERMINING INPUT ENERGY FROM ENERGIES OF SECONDARY PARTICLES IN n + ^{1}H → n+ p REACTION

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In [1], the possibility of obtaining a quasi-monoenergetic beam of fast neutrons using quasi-monoenergetic photons in the $\gamma + {}^9\text{Be} \rightarrow {}^8\text{Be} + \text{n}$ reaction was shown. Thus for quasi-monochromatization of a photon beam spectrum the procedure based on irradiation of a bremsstrahlung target by electrons of different energies was used [2]. To test this technique, it is necessary to study the neutron spectra at different energies of the primary electron beam. If the parameters of the neutron beam are sufficiently good it will be possible to create an experimental setup for measuring neutron cross sections at neutron energy of ~1–3 MeV.

To determine the fast neutron spectrum, we use the elastic neutron scattering reaction on hydrogen $\text{n} + {}^1\text{H} \rightarrow \text{n} + \text{p}$. The energy of the primary neutron is obtained as a sum of the secondary proton and neutron energies. The energy of the secondary proton is determined from the energy deposited in a silicon surface barrier detector. The neutron energy is determined by the time of flight (TOF) of the secondary neutron on the base of 1 m. At that, the starting signal for TOF will be the signal from the Si-detector.

Hydrogen-containing CH_2-target was placed at an angle of 70° related to the electron beam axis at a distance of 1.5 m from the Be neutron target. The proton detector (~300 μm thick silicon surface barrier detector) was mounted at one end of the vacuum tube, the other end of the tube was closed by the CH_2 target. EJ-301 CH-scintillator allowing n-γ pulse shape discrimination was used as the neutron detector at a distance of 1 m from the CH_2 target. Both proton and neutron detectors are surrounded by a massive lead shield. The signals of the two detectors are digitized using the digital signal processor CAEN DT5720. The spectrum of the incident neutrons is obtained from the coincident signals of the detectors.

The results of measurements for various energies and intensities of the primary electron beam are presented. The possibility of different measurements of neutron cross sections and possible variants of experimental setups are discussed.

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PHOTO-EXCITATION OF Cd AND In NUCLEI BY REAL AND VIRTUAL PHOTONS IN THE 4 – 9 MeV ENERGY REGION

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New experimental results on photo-excitation of the Cd and In spin isomers by real and virtual photons (electrons) are presented. The measurements were performed using electron linac LUE-8-5 (Institute for Nuclear Research of RAS) in the energy range of 4–9 MeV. The measurements with real bremsstrahlung photons were performed using 0.4 mm thick tungsten radiator. When measuring the reaction yield with virtual photons (electrons), the radiator was removed from the beam.

The cross-section per equivalent photon (σ_q) and the electron cross section (σ_e) were determined measuring a yield of induced gamma activity after an irradiation on the beam. The samples were placed in a low-background camera equipped by a high-purity germanium detector (HPGe) [1]. The typical activation spectrum of ^{111m}Cd is shown in Fig. 1.

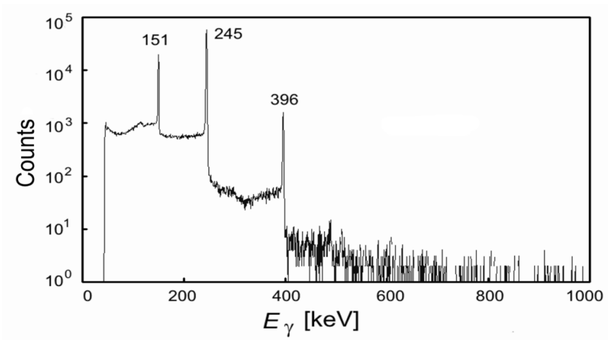

Fig. 1. Activation spectrum of ^{111m}Cd isomeric states in (γ,γ’) reaction.

The measurement procedure and preliminary results for 7.5 MeV are given earlier in [2]. The data obtained at different energies of real and virtual photons are discussed.

This work is supported by Russian Scientific Fund, grant №16-12-10039.

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STUDY OF THERMAL NEUTRON SPECTRUM OF THE W-Be PHOTONEUTRON SOURCE OF INR RAS

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A W-Be photoneutron source IN-LUE on the base of linear electron accelerator was created at the Institute for Nuclear Research of the Russian Academy of Sciences [1]. The neutron spectrum of the source contains contributions from thermal, epithermal, and fast neutrons. The form of the spectrum and the neutron flux estimation were estimated earlier as a result of simulation.

In this paper, the results of reconstructing the thermal part of the neutron spectrum are presented. Data on the neutron activation analysis of Ag, Fe, Mg, Mn, and Ti samples irradiated by the source neutrons were used as experimental data for reconstructing. A comparative analysis of neutron capture cross sections on these nuclei and convolution of cross sections with different energy regions of the model spectrum indicates a noticeable contribution to the measured values only of thermal neutrons. The activation spectra were measured using a low-background gamma spectrometer [2]. An estimate of the neutron flux density in the thermal region of the source neutron spectrum was made.

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A SETUP FOR CHARGED PARTICLES AND NEUTRONS DETECTION FOR STUDY p, d AND ^{4}He REACTIONS ON LIGHT NUCLEI

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An experimental setup intended for studying reactions induced by protons, deuterons and alpha particles on light nuclei is described. This setup was installed at the charged particle beam of the U-120 cyclotron of SINP MSU, and includes a scattering chamber with a target allowing one to change and rotate targets, a Δ*E*-*E* telescope of silicon detectors, and neutron detectors. The charge particle telescope consists of 3 silicon detectors, for example, 24, 415 and 315 μm thick, and could be rotated allowing to obtain data in angular region from θ_{lab}= 30° to θ_{lab}=160° in steps of 10°. As a neutron detector hydrogen-containing scintillation detectors (EJ-301 or EJ-315 type) were used. The data acquisition system is based on CAEN DT 5720 and DT 5742 digital signal processors. Such a configuration allows us to obtain all necessary information using a minimum set of electronic blocks, while the processing of digitized signals provides broad opportunities for interpretation of obtained data.

The reported study was funded by RFBR according to the research project № 18-32-00944.

STUDY OF LIGHT NUCLEI CLUSTER STRUCTURE IN d-^{9}Be INTERACTION

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Energy spectra of protons, deuterons, tritons and alpha-particles emitted from reactions induced by deuterons on ^{9}Be-target were measured. Experiment was performed using 15 MeV deuteron beam of U-120 cyclotron at Skobeltsyn Institute of Nuclear Physics. The energy spread of the beam was about 160 keV. The average beam current during the experiment was about of 5 nA. The self-supporting Be target was prepared from a 99% pure thin foil of beryllium. The target thickness was 0.9 mg/cm^{2}.

To measure the scattered charged fragments a telescope consisting of three Si detectors with thicknesses of 24, 415 and 315 μm was used. Particle identification was performed based on the ΔE-E_1 and E_1-E_2 loci. The Si telescope was rotated, which allowed to obtain data from θ_{lab}= 30° to θ_{lab}=160° in steps of 10°.

Angular distributions of the differential cross sections for the ^{9}Be(d,d)^{9}Be, ^{9}Be(d,p)^{10}Be, ^{9}Be(d,t)^{8}Be, ^{9}Be(d,α)^{7}Li reactions for the ground state and few low-lying states were measured. Experimental angular distributions were analyzed in the framework of distorted wave Born approximation with interference of different reaction channels.

The reported study was funded by RFBR according to the research project № 18-32-00944.

FISSION OF $^{235,238}U$ AND ^{232}Th NUCLEI BY REAL AND VIRTUAL PHOTONS IN THE THRESHOLD ENERGY REGION

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New experimental results on photo-fission of $^{235,238}U$ and ^{232}Th nuclei by real and virtual photons (electrons) in the threshold energy region are presented. The measurements were performed using electron linac LUE-8-5 (Institute for Nuclear Research of RAS) in the energy range of 4–9 MeV. The energy resolution of the electron beam was improved from 5 to 0.8 % (FWHM) due to the magnetic system deflecting the beam on 270^o. The measurements with real bremsstrahlung photons were performed using 0.4 mm thick tungsten radiator. When measuring the reaction yield with virtual photons (electrons), the radiator was removed from the beam.

The photo-fission cross-section per equivalent photon (σ_q) was determined measuring a yield of delayed induced gamma activity after an irradiation on the beam. The samples were placed in a low-background camera equipped by a high-purity germanium detector (HPGe) of 130 cm^3.

The data obtained at different energies of real and virtual photons are discussed in frame of the phenomenological model which allows the theoretical evaluation of σ_q/σ_e cross sections in this energy and mass region.

This work is supported by Russian Scientific Fund, grant no. 16-12-10039.

EXPERIMENTAL STUDIES OF π^0 AND η MESON PRODUCTION IN U+U COLLISIONS AT 192 GeV

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The study of heavy ion collisions at the RHIC collider led to experimental confirmation of the production of a strongly interacting quark-gluon plasma (sQGP) [1], a state of nuclear matter under extreme temperature and density with partonic degrees of freedom. Since then, the main effort of RHIC experiments [2] lies in detailed study of the new state of matter using more accurate and universal methods of measurement.

One of the signatures of sQGP formation is jet quenching. Hard partons lose part of their energy traversing through quark-gluon medium, which leads to a decrease in the hadron yield, in comparison to their yield in proton-proton collisions, scaled to the number of binary collisions. Thus, measuring the level of hadrons yields suppression at high transverse momenta is an opportunity to study the mechanisms of parton energy loss in the sQGP.

Jet quenching effect in nuclear collisions is quantitatively measured using the nuclear modification factor, which is calculated as the ratio of hadron yields in heavy ion collisions and the yields of these hadrons in p+p collisions, normalized to the number of binary nucleon-nucleon collisions.

The yields of π^0 and η mesons can be measured with fine precision in a wide range of transverse momentum. The system of U+U collisions provides highest energy density accessible at RHIC so far, which makes it interesting for studying of the jet quenching effect. Measurements of invariant production spectra and nuclear modification factors for π^0 and η mesons in U+U collisions are a part of a systematic study of sQGP properties and will put additional restrictions on theoretical predictions for the jet quenching effect and describe partonic energy loss in more detail.

This report presents invariant transverse momentum spectra and nuclear modification factors of π^0 and η mesons measured in the U+U collision at $\sqrt{s_{NN}}$ = 192 GeV. The values of the nuclear modification factors of π^0 and η mesons are similar in the measured transverse momentum range and centrality within the uncertainties. In central U+U and Au+Au collisions, the yields of η mesons are equally suppressed within the uncertainties. In peripheral U+U collisions, the yields of η mesons are more suppressed than in Au+Au collisions.

We acknowledge support from Russian Ministry of Education and Science, state assignment 3.1498.2017/4.6.

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EXPERIMENTAL STUDIES OF K_S AND ω MESON PRODUCTION IN Cu+Au COLLISIONS AT 200 GeV

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Strongly interacting quark-gluon plasma (sQGP) [1] is a deconfined state of nuclear matter under the extreme conditions of temperature and baryon density, which was first observed in the collisions of ultrarelativistic heavy-ion collisions in the experiments at RHIC[2–5]. Today the mission of PHENIX experiment [6] at RHIC is to provide detailed information on sQGP properties and evidences.

Jet quenching [7] is one of the evidences for sQGP formation, which is related to the energy loss of high energy partons observed and followed by suppressed production of yields of hadrons at high transverse momenta ($p_T > 5$ GeV/c) when compared to the yields measured in elementary p+p collisions and scaled by the number of binary inelastic nucleon-nucleon collisions. Numerically this effect is usually studied with nuclear modification factors (R_{AA}) measured as a function of the particle transverse momentum and the collision centrality.

The capability of PHENIX spectrometer allows to measure K_S and ω mesons yields in a wide transverse momentum range with relatively small uncertainties. Study of these particles production at high transverse momenta serve as an excellent systematic probe of the jet-quenching dependent on the particle flavor, mass and spin.

RHIC provides a large variety of different heavy-ion collision systems. Cu+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV is the first asymmetric heavy ion collision system available for the analyses and provides a special collision geometry different from symmetric systems (Au+Au and Cu+Cu). Measurements of neutral meson production in Cu+Au collisions can provide a better discrimination on the parameters of the jet-quenching models and more detailed information on the parton energy loss mechanisms.

In this report we present the results on K_S and ω mesons transverse momentum spectra and nuclear modification factor measurements in different centrality intervals of Cu+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV.

We acknowledge support from Russian Ministry of Education and Science, state assignment 3.1498.2017/4.6.

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INFLUENCE OF NUCLEAR TEMPERATURE ON ISOSCALING PARAMETER IN PHOTOFISSION

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Isoscaling is the exponential dependence of the ratio of the yields of *R* isotopes with the same number of neutrons *N* and protons and *Z* from two different targets 1 and 2:

$$R(N,Z) = Y_1(N,Z) / Y_2(N,Z) = C\exp(\alpha N + \beta Z),$$

where *C* is the normalization coefficient, and α and β are the parameters of isoscaling.

Our earlier attempt to extract information on the temperature of the fissioning nuclear system from the isoscaling parameters in the yields of Kr and Xe fragments from the photofission of nuclei in the light actinide region [1] show the strong shell effect in the region of asymmetric peaks in the distribution of mass of fission products, arising under the influence of neutron spherical shell $N = 82$ and deformed shell $N = 88$.

In this paper we calculate the values of isoscaling parameters in the framework of liquid drop model, using the fact that the masses of all Kr and Xe isotopes whose yields are measured by us and almost all the fission fragments associated with them are known from experiments, and several remaining ones were calculated with good accuracy [2].

The use of tabular data does not allow us to obtain an analytical expression for the dependence of the isoscaling coefficients on the temperature of the fission. Therefore, we calculated the value of R_{teor} (N,Z) for a different temperatures. Calculated values show the strong dependence from temperature, which made it possible to estimate of the temperature of the fissioning nuclei when compared with the experimental R_{exp} (N,Z).

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ISOMERIC CROSS SECTION RATIOS FOR THE NUCLEAR REACTION $^{41}K(\alpha,n)^{44mg}Sc$

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The calculations of the excitation functions of high-spin and low-spin isomeric States production in one and the same nucleus as well as the respective isomeric cross section ratios (ICSR) were carried out for reaction $^{41}K(\alpha,n)^{44mg}Sc$. Measurements of ICSR allow one to obtain reliable information on angular momentum dynamics of a preceding reaction and spin dependence of nuclear level density. This dynamics depends on the properties of a target, projectile and emitted particles. Experimental studies of ICSR produced by reaction $^{41}K(\alpha,n)^{44mg}Sc$ in the α-particle energy ranges 14–32 MeV were carried out by us earlier using off-beam measurements of induced activity of members of the isomeric pair. Calculations of ICSR for the indicated reaction are performed using the codes EMPIRE-3 and TALYS. For the discussed conditions the values of ICSR calculated by EMPIRE-3 are in disagreement with experimental ones being 20–30 % greater. At higher energies of α-particles calculated values of isomeric ratios significantly exceed experimental ones. As for the data obtained by use of TALYS code they turn to be in a good agreement with experimental ones over all measured region except the expressive experimental maximum of ICSR at energy 26 MeV.

ANGULAR p-γ-CORRELATION IN THE REACTION $^{13}C(d, p_3\gamma)^{14}C$ (3^-; 6.73 MeV)

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Double-differential cross sections of the reaction $^{13}C(d,p_3\gamma)^{14}C$ at E_d = 15.3 MeV were measured for 3 proton emission angles 30, 60 and 120° (lab.) on the SINP MSU 120-cm cyclotron. The angular correlation functions $W(\theta_\gamma, \varphi_\gamma; \theta_p)$ (ACF) were carried out for 9 polar angles θ_γ in the interval 20–150° on a four planes φ_γ of γ-rays registration for each angle θ_p. On the ACF basis we reconstructed the angular dependences of all 16 density matrix even spin-tensor components $A_{k\kappa}(\theta_p)$ of the final nucleus $^{14}C(3^-$; 6.73 MeV) for each angle θ_p. The values obtained for $A_{k\kappa}(\theta_p)$ were used to determine other orientation features of the final-state nucleus: the populations $P_{\pm M}(\theta_p)$ of sublevels characterized by the projection M of the spin 3^- final-nucleus state (points in Fig. 1) and the rank k orientation tensors $t_{k\kappa}(\theta_p)$ for the multipole moments with respect to the symmetry axis of the nucleus (momentum of the recoil nucleus).

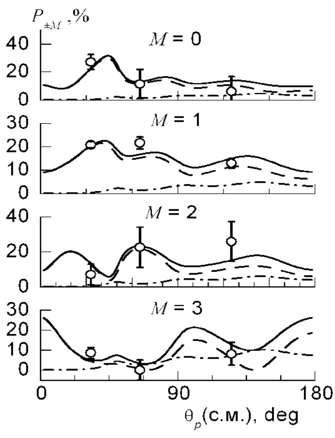

Fig. 1. The populations $P_{\pm M}(\theta_p)$ of sublevels $^{14}C(3^-)$ nucleus. Solid curve – the sum of the mechanisms examined.

Experimental data were compared with theoretical results, obtained for the neutron stripping mechanism by the coupled-channel method (code FRESCO [1], dashed curve in fig. 1) and for the compound nucleus statistical mechanism (code CNDENSY [2], dash-dot curve).

Our model analysis of angular correlations in the reaction $^{13}C(d, p_3\gamma)^{14}C$ at E_d = 15.3 MeV has revealed that its dominant mechanism is associated with neutron stripping mechanism and a collective excitation of residual nucleus. The mechanism of the compound nucleus is noticeable only at large angles of proton emission.

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TOTAL REACTION CROSS SECTIONS FOR ^{6,8}He, ^{8,9}Li, $^{7,9-12}$Be NUCLEI ON Si AND Ta

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The total nuclear reaction cross sections σ_R measurements have long been of interest since they tell us about the radii of these nuclei and give some clues to understanding of their structure. The first data on the interaction cross section σ_I, for unstable nuclei [1] were obtained at 800 *A*·MeV energy which includes only those reactions which destroy the projectile but excludes target reactions which leave the projectile intact.

Preliminary results of measurements of the total reaction cross sections σ_R for weakly bound ^{6,8}He, ^{8,9}Li, $^{7,9-12}$Be nuclei at energy range (25–45)/*A*·MeV on ^{28}Si and ^{181}Ta targets are presented. These secondary beams were obtained by a fragmentation of a primary ^{15}N beam at 50 *A*·MeV and intensity up to 1 pμA by the U-400M cyclotron of the Flerov Laboratory of Nuclear Reactions. The COMBAS fragment-separator was used for purification of the secondary beam ions. They were detected by a telescope consisting of five Si ΔE detectors 100, 620, 300, 300, 500 μm and *E* detector (CsI/Tl) with thickness 15 mm (Fig 1.).

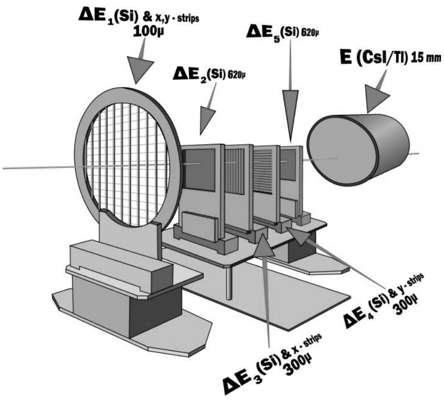

Fig 1. The detector system.

Our goal is to study total reaction cross sections σ_R by a direct measurement technique (the so called beam attenuation or transmission method) which allows to extract model independent information [2].

Preliminary results of the total reaction cross section measurement on Si and Ta targets are presented.

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SPLITTING OF FRAGMENTATION PEAKS IN ^{56}Fe + ^{9}Be COLLISIONS AT 0.23 GeV/NUCLEON

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Momentum distributions of nuclear fragments at 3.5° from 0.23 GeV/nucleon ^{56}Fe fragmentation on Be target were measured in the FRAGM experiment [1] at the ITEP-TWA heavy ion facility. The momentum spectra of projectile like fragments were measured with high resolution beamline spectrometer. Fragments were selected by correlated time of flight and dE/dx measurements with scintillation detectors. In contrast to the carbon fragmentation [2], where the momentum spectra have Gaussian-like shapes, in the fragmentation of iron ions into the light fragments the shapes have a double-humped structure. This splitting is most pronounced in proton spectra, decreases with increasing fragment mass and disappears for lithium isotopes and heavier fragments. The possibility of describing this effect in coalescence model, asymmetric fission, multi-fragmentation, etc. is discussed. A comparison is made with the results of the FRS measurements in GSI [3], where a similar effect was observed in the fragmentation of iron and xenon ions into lithium and boron isotopes at 1 GeV/nucleon. A comparison is made with the predictions of several transport codes. The importance of taking this effect into account in fragmentation methods for luminosity measurement at the NICA collider is pointed out.

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THE BREMSSTRAHLUNG SPECTRA REPRESENTATIONS AND RELATED YIELDS OF PHOTONUCLEAR REACTIONS

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Two sorts of comparison were considered for the most used representations of important values at experimental photonuclear studies of the giant resonances in atomic nuclei with bremsstrahlung photons. The first one is connected with the differential only in photon energies k cross sections ($d\sigma_b/dk$) of bremsstrahlung production by electrons with a total energy E in radiators (having an atomic number Z) as by L.I.Schiff $(d\sigma_b/dk)_{Sch}$ [1], as by S.M.Seltzer and M.J.Berger $(d\sigma_b/dk)_{S\text{-}B}$ [2] with usage of the approximate representations for ratios of these cross sections $(d\sigma_b/dk)_{S\text{-}B}/(d\sigma_b/dk)_{Sch}$ at the same values of E and k from [3]. The second one is for spectra of produced total bremsstrahlung photon fluxes $\Phi(E,k,Z)dkdx_r$ from an element dx_r of radiator thickness having radiation length $X_{0\,r}$ [4] (corresponding to these cross sections, see also the approximation for these spectra $\Phi(E,k,Z)dkdx_r \approx (dx_r/X_{0\,r})(1/k)dk$ in [4, 5]).

For all pointed out above photon fluxes and for an element of photonuclear target thickness dx_t there were considered the integral functions based on convolutions of these fluxes with the model cross sections $\sigma(k)$ for the characteristic reactions ^{68}Zn(γ,p)^{67}Cu (I) (used for production of ^{67}Cu for nuclear medicine), and also ^{14}N(γ,2n)^{12}N (II) and ^{14}N(γ,2p)^{12}B (III) (used in the photonuclear method under development for detection of hidden explosives (see, e.g., [6])). Namely yields $Y(E-\mu)dx_t dx_r \equiv dx_t dx_r \int_0^{E-\mu} \Phi(E,k,Z)\sigma(k)dk$, where μ is the total electron rest energy, and cross sections per an equivalent quantum $\sigma_q(E-\mu) \equiv \left[\int_0^{E-\mu} \Phi(E,k,Z)\sigma(k)dk\right] \Big/ \left[(1/(E-\mu)) \int_0^{E-\mu} k\Phi(E,k,Z)dk\right]$ for these reactions. The model cross section for the reaction (I) was calculated in this work using the method described in [7]. The model cross sections for the reactions (II) and (III) were taken from [8].

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ESTIMATION OF $^{238}U(\gamma, f)$ AND $^{238}U(\gamma,n)$ REACTIONS CROSS SECTIONS

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Experimental study of nuclear fission is of high importance both for applied and theoretical purposes, therefore fission is one of the most investigated process in nuclear physics. However, main attention is paid to fission under thermal and fast neutrons due to apparent practical applications, and other areas lack accurate data. Photon-induced fission or photofission is one of such bypassed areas despite its wide potential for applied developments.

The cross sections for photofission and competing photoneutron reactions on the ^{238}U have been measured mainly on quasi-monochromatic gamma ray beams by the neutron multiplicity method. There are significant differences between parameters of these cross sections obtained in different laboratories: the form of a spectrum, the amplitude and position of the maximum [1, 2]. The optimal method to revise the data and estimate the cross sections of these reactions is the one that allows fission fragments to be directly measured.

The results of the measurement of the absolute yields of the $^{238}U(\gamma,n)$ reaction and the photofission $^{238}U(\gamma,f)$ on a bremsstrahlung gamma-ray beam at a maximum energy of 55.6 MeV are presented. In order to determine the yields of the photofission and the photoneutron reactions a gamma-activation technique of measuring the induced activity of the reaction products was used. A reaction on the copper monitor was used to measure the flux of gammas and the absolute values of the yields. The yield of the photofission reaction was obtained by measurement of the accumulated yields of the fission fragments at the end of the beta-decay chain of the isobar nuclei. 40 decay chains were analyzed for this purpose.

The estimation of $^{238}U(\gamma,f)$ and $^{238}U(\gamma,n)$ cross sections based on the obtained data was made.

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EVALUATION OF THE Li(n,α)t REACTION CROSS SECTION

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In the given work is held analysis and evaluation available experimental data over the cross section for the reaction Li(n,α)t in order to obtain the recommended data. The cross section for the reaction Li(n,α)t – $\sigma_{n\alpha}(E_n)$ in neutron physics used frequently as a reference value. In the neutron energy range E_n from 0.025 eV to 100 keV, the cross section is known with an accuracy of 1 ÷ 3%. In the energy range of 0.5 ÷ 1.7 MeV the accuracy is about 15%. As for the energy interval from 100 keV to 500 keV, here due to strong resonance about neutron energy of 250 keV exist significant uncertainties. In the estimate of [1] for this region energies were recommended cross-sectional values of $\sigma_{n\alpha}(E_n)$, obtained from condition the best description of the total cross section, cross section for elastic scattering of neutrons and reaction cross sections (n,α). In the last years was appeared new data over the cross section for the reaction Li(n,α)t. Specially, the stroke was explored in detail in the energy range of 100 ÷ 500 keV. As noted at the meeting on neutron data, the results performed in the energy range of 150 ÷ 400 keV agree among themselves within ± 4%, if we recognize a systematic shift in energy (about 5 keV) of the results of the work and renormalize the cross sections, received in work [2] down by 5%.

In this paper, was comparing the results of the parameterization of the experimental data for the energy range 2 keV ÷ 1.5 MeV by the method of least squares using a number of different approximations. As the first approximation, were used the expression including the resonance term in the 1/ν (1) dependence:

$$\sigma_{n\alpha}\left(E_n\right)=\frac{A\sqrt{E}}{\left(E-E_0\right)^2+\left(\Gamma/2\right)^2}+\frac{B}{\sqrt{E}}-\Delta\sigma \qquad (1)$$

Here *A* and *B* are constants, E_0 is the resonance energy, Γ is the width of the resonance, *A*, *B*, *E* and Δσ are the fitting parameters. As a result of the processing, the following values were obtained for them: $A = 0.0141$; $B = 0.1350$; $E_0 = 0.2410$; $\Gamma = 0.1050$ and $\Delta\sigma = 0.0260$. In this case, the value of χ^2 at the point averaged over the region 2 ÷ 1500 keV was 3.5, and the standard deviation δ_0, calculated as $\delta_0=\sqrt{\left(\sigma_{calc}-\sigma_{exp}\right)^2/\sigma_{exp}^2}\cdot 100\%$ and averaged over the same energy range, was 7.5%. The calculation results, with the experimental datas, are given in the papers [2, 3]. In the energy range of 2 keV ÷ 500 keV, expression (1) describes the experimental data as quite well. For $E_n \leq 500$ keV the description is much worse.

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ESTIMATION OF ELASTIC SCATTERING OF NEUTRONS BY SILVER IN THE OPTICAL MODEL

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The question of the possibility of improving the data on elastic neutron-silver scattering by adding to the potential an optical model of a long-range term of the type const/r^4, presumably of an electromagnetic nature, was discussed. The optical potential of the complicated form is investigated in a discrete approximation for neutrons with energies from 0.5 keV to 14 MeV. It was shown that the description of the elastic cross sections for small angular scattering at neutron energies of 1 ÷ 5 MeV is markedly improved when long-range action is introduced ~ $0.5\cdot10^{-41}$ cm^3.

The best description of the angular distributions was obtained for α=0, the numerical value of the corresponding quadratic functional increases by only 12% when α varies from 0 to $1\cdot10^{-41}$ cm^3. The corresponding discrete sets of dynamic parameters were given in the table. Significant changes in the parameters with the introduction of $\alpha = 1\cdot10^{-41}$ cm^3 are not occur [1, 2].

The parameters of the potential suitable for calculations in the neutron energy range 0.5÷300 keV were given.

$V_1 = 23.5 - 8.76\ E_n$ (MeV)	$a_1 = 0.165$ fm	$R_1 = 8.145$ fm
$V_2 = 26.85 - 17.13\ E_n$ (MeV)	$a_2 = 0.43$ fm	$R_2 = 6.97$ fm
$W_{s1} = 1.12 + 0.21\ E_n$ (MeV)	$b_1 = 0.53$ fm	$R_{w1} = 6.85$ fm
$W_{s2} = 1.57 + 1.46\ E_n$ (MeV)	$b_2 = 0.53$ fm	$R_{w2} = 7.86$ fm
$X = 0.0003 + 0.055101\ E_n$ (MeV)	$V_{s0} = 13.11$ fm	$\alpha = 0$

Optical parameters for low neutron energies

E_n, keV	V_1, MeV		V_2, MeV		V_{s1}, MeV		V_{s2}, MeV	
	0	0.7	0	0.7	0	0.7	0	0.7
0.5	22.15	23.02	26.88	26.54	0.13	0.15	0.68	0.91
0.55	23.46	25.15	28.15	27.15	0.17	0.15	0.17	0.82
1.61	25.42	25.85	25.37	25.31	0.18	0.26	1.26	1.35
86.00	23.85	23.73	24.83	24.53	1.13	2.17	1.80	1.73
100.00	23.85	23.65	24.47	24.25	1.50	1.60	1.75	1,76
150.00	23.85	23.50	24.67	23.97	2.20	1.72	1.72	2.21
225	23.85	23.45	24.21	23.97	2.75	1.96	1.00	2.15

For different values of the coefficient α for fixed geometric parameters of the nuclear potential, discrete sets of dynamic parameters that best describe the set of experimental data are founded.

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NEW PHOTONEUTRON REACTION CROSS SECTION DATA FOR ^{153}Eu AND ^{165}Ho

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The analysis of significant systematic disagreements between the results of various photonuclear experiments was carried out for ^{153}Eu [1] and ^{165}Ho [1, 2] experimental data obtained using the beams of quasimonoenergetic annihilation photons and the method of photoneutron multiplicity sorting.

The simple objective physical criteria of data reliability – ratios $F_i = \sigma(\gamma,in)/\sigma(\gamma,xn) = \sigma(\gamma,in)/[\sigma(\gamma,1n) + 2\sigma(\gamma,2n) + \ldots]$, which have values not higher than 1.00 and 0.50, correspondingly were introduced [3]. For both nuclei it was shown that experimental data are not reliable because one can see many physically forbidden negative values of (γ,1n) reaction cross sections and correlated with those (γ,2n) reaction cross sections for which $F_2 > 0.50$.

The experimentally-theoretical method [3, 4] was used for reliable partial reaction cross section data evaluation. In this treatment only experimental data for neutron yield cross section $\sigma^{exp}(\gamma,xn)$, free from the neutron multiplicity sorting problems, was used for partial reaction cross section evaluation together with functions F_i^{theor}, calculated in the frame of the combined model of photonuclear reactions [5, 6]. Additionally $\sigma^{exp}(\gamma,xn)$ data obtained using bremsstrahlung [7, 8] were used for analysis.

Evaluations of new reliable photoneutron reaction cross section data were carried out for both nuclei for partial reactions (γ,1n), (γ,2n) and (γ,3n) and for total photoneutron reaction (γ,*s*n) = (γ,1n) + (γ,2n) + (γ,3n). The noticeable disagreements between evaluated and experimental data were obtained and analyzed.

The research was carried out in the Department of Electromagnetic Processes and Atomic Nuclei Interactions of the MSU SINP. It is supported by the Coordinated Research Project (F41032, the Research Contract 20501) of the International Atomic Energy Agency.

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EVALUATION OF RELIABLE PARTIAL AND TOTAL PHOTONEUTRON REACTION CROSS SECTIONS FOR ^{145,148}Nd

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Experimental data on partial and total photonuclear reaction cross sections for nuclei ^{145,148}Nd obtained at Saclay (France) using quasimonoenergetic annihilation photons and the neutron multiplicity sorting based on its energy measurement [1] were analyzed. The analysis was based on the objective physical criteria of data reliability – ratios $F_i = \sigma(\gamma,in)/\sigma(\gamma,xn) = \sigma(\gamma,in)/[\sigma(\gamma,1n) + 2\sigma(\gamma,2n) + \ldots]$, which have values not higher than 1.00 and 0.50 [2]. In many research carried out before for many medium and heavy nuclei it was shown that values $F_2 > 0.50$ and $F_1 < 0$ mean that experimental neutron multiplicity sorting has been done erroneously because of large systematic uncertainties. The third criterion of data reliability was found [2, 3] on the base of comparison of experimental F_i^{exp} with F_i^{theor}, calculated in the frame of the combined model of photonuclear reactions [4, 5]. It was shown that if F_i^{exp} noticeably differ from F_i^{theor} one has definite doubts in experimental data reliability.

For both isotopes ^{145,148}Nd it was shown that experimental data are not reliable. Therefore new reliable partial photoneutron reaction cross sections were evaluated using the experimentally-theoretical method [2, 3]: $\sigma^{eval}(\gamma,in) = F_i^{theor}\cdot\sigma^{exp}(\gamma,xn)$. It means that competition between partial reactions is in accordance with the model and their sum $\sigma^{eval}(\gamma,xn)$ is equal to $\sigma^{exp}(\gamma, xn)$ free from neutron multiplicity sorting problems. It was found that there are noticeable disagreements between evaluated and experimental data. It is shown that those deviations are the results of unreliable and erroneous redistribution of many neutrons between the channels with multiplicities “1” and “2”.

Since the newly evaluated data noticeably differ from Saclay experimental data, a discussion of the physical consequences is needed.

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ENERGY DEPENDENCE OF TOTAL REACTION CROSS SECTIONS FOR $^{6,8}He$ + Si AND $^{9,11}Li$ + Si COLLISIONS

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A series of experiments on measurement of total cross sections for reactions ^{6,8}He + Si and ^{9,11}Li + Si in the beam energy range 5–50 A·MeV was performed at Flerov Laboratory of Nuclear Reactions (FLNR), Joint Institute for Nuclear Research (JINR). The transmission method based on registration of energy loss in the material of ΔE detector (natural Si target) as well as registration of n-γ radiation by the 4π spectrometer was used.

The interesting results were the unusual wide enhancement of total cross section for ^{9}Li + Si reaction in the energy range ~10–30 A·MeV as compared with ^{6,7}Li + Si reactions. The similar weaker behavior was found for ^{6}He + Si reaction as compared with ^{4}He + Si reaction.

The microscopic approach based on the numeric solution of the time-dependent Schrödinger equation for the external neutrons of weakly bound projectile nuclei combined with the optical model is used for description of the observed effects. The calculated cross sections are in agreement with the experimental data on the total reaction cross sections for the studied nuclei.

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POPULATION OF ^{177m}Lu IN REACTION WITH BREMSSTRAHLUNG PHOTONS

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To date, the (γ,α)-reactions with bremsstrahlung γ-quanta have not been sufficiently investigated at significant difference between the spins of the isomeric and the ground states of the residual nucleus. In this case, the excited levels that are often not available for (γ,n)-channel can be excited. By studying the population of high-spin *K*-isomers, can obtain additional information about the structure of these excited levels and mechanisms of the nuclear reactions. One of these isomers is the ^{177m}Lu – three quasiparticle isomeric state (E^* = 0.97 MeV, $T_{1/2}$ = 160.4 d., $J^{\pi} = 23/2^{-}$), and therefore the purpose of our work is to study the cross section for the production of ^{177m}Lu in the (γ,α)-reaction.

The irradiation was carried out using the LUE-40 electron accelerator of the Kharkiv Physical Technological Institute at the endpoint bremsstrahlung energy 37 MeV. The activity measurements were carried out in a separate low-background laboratory using γ-spectrometers based on the HPGe-detectors with an energy resolution of 1.8 ÷ 2 keV on γ-lines of ^{60}Co and relative efficiency of 15 ÷ 40% in comparison with a 3″×3″ NaI(Tl)-detector.

In the spectra, γ-transitions are observed from ^{177m}Lu decay. The photon flux distributions were calculated by using the Geant4 and MCNP codes for the real experimental geometry. Though the results of modeling are similar for both codes, we used the Geant4 as it is more modern. The resulting value of the integral cross section is $\sigma^{int} = (9.7 \pm 0.7) \times 10^{-30}$ cm^2.

The theoretical calculation of the ^{177m}Lu integral cross section was carried out within the framework of the codes TALYS-1.6 and EMPIRE-3.2. Although the results calculated in EMPIRE-3.2 are much closer to the experimental values at using the default parameters, however, full agreement between the theory and the experiment was not found. This may indicate a significant contribution to the cross section of the population of the isomeric state of the direct and semi-indirect processes that are not taken into account in the above codes.

The discussion is transacted about obtained data.

HOYLE-STATE IN DISSOCIATION OF RELATIVISTIC ^{12}C NUCLEI

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Events of dissociation of relativistic nuclei in nuclear track emulsion (NTE) allow a holistic investigation of “cold” ensembles of lightest nuclei. So far, with regard to fine structure dissociation of relativistic nuclei, the NTE technique remains the only means providing unique completeness of such observations at the best angular resolution and as well as a sufficient statistical provision. Moreover, full-bodied studies of light nuclear structure require reconstruction of relativistic decays of the unstable ^{8}Be and ^{9}B nuclei. Feasibility of such studies in electronic experiments is not visible at all. The cluster structure of light nuclei and the role of the unstable ^{8}Be and ^{9}B nuclei in them is studied in the BECQUEREL project (http://becquerel.jinr.ru) on the basis of NTE layers longitudinally exposed at the JINR Nuclotron to relativistic Be, B, C and N nuclei, including radioactive isotopes [1]. Recent advances are highlighted [2–4]. On the practical side series of experiments with newly reproduced samples NTE has confirmed prospects of NTE in low and high energy nuclear studies [5].

Recently it is suggested to search in relativistic ^{12}C dissociation for α-particle triples in the second excited state 0^{+}_{2} of the ^{12}C nucleus (the Hoyle state). The started study of the Hoyle-state (HS) in dissociation is setting new limit of NTE use. Being performed in contrast to relativistic energy of 3α-ensembles and minimum possible energy stored by them such observations would clearly demonstrated HS as a full-fledged and sufficiently long-lived nuclear-molecular object. Probably, not only single but also pair- and even triple-wise combinations of α-particles that are close to ^{8}Be might be observed to reflecting the HS structure in less distorted way. It can be expected that ^{8}Be and HS will become reference points to search for more complex states of dilute nuclear matter in dissociation of heavier relativistic nuclei. The current experiment task is to search for several hundreds of 3α-events in NTE pellicles and measure the angles of α-particles in the relevant ranges with a resolution allowing reconstructing decays of the unstable ^{8}Be nucleus and HS (example in Fig. 1). HS events are observed in dissociation ^{12}C → 3α at 4.5 *A*·GeV/c and 1 *A*·GeV/c ^{12}C nuclei with a contribution preliminary estimated to be of the order of 10%. Thus, the first data on relativistic HS are encouraging.

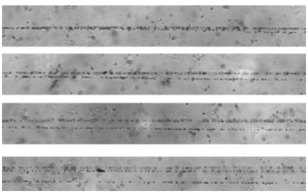

Fig. 1. Sequential shots of coherent dissociation ^{12}C → 3α at about 1 A GeV/c (from top to bottom); when moving from the vertex three He fragments can be distinguished. Values of the invariant mass of the α-pairs are 57, 60 and 270 keV. Invariant mass of the α-tiple is 230 keV while its total transverse momentum 111 MeV/c.

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ANALYSIS OF COMPUTATIONAL METHODS OF DETERMINATION OF ALPHA-PARTICLE SPECTRA, PASSING THROUGH THE THIN LAYERS OF MATTER

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The spectra of heavy charged particles passed through thin layers of matter are determined by the average energy loss of the particles and their fluctuations. To describe the fluctuations in thin layers, Vavilov obtained a distribution [1], which is a generalization of the Landau distribution. The distribution of Vavilov, unlike the Landau distribution, depends on the velocity of the particle and on the ratio κ of the average energy loss in the layer to the maximum energy transferred to the atomic electron in the collision. It is known that the asymptotics of the Vavilov distribution as $\kappa \to 0$ is the Landau distribution, and for $\kappa \gg 1$ the normal distribution. The purpose of this paper was to study the conversion from the Vavilov distribution to the Gaussian asymptotic under controlled conversation error. This makes possible to establish the limit thickness of the layer to use the normal distribution at a certain alpha-particle energy. The calculations were done for alpha particle energy of 5.495 MeV, corresponding to the alpha decay of ^{238}U and aluminum foil. The thickness of foil is denoted as *Z*. To compare the distributions of Vavilov and the normal one, the method of moments was used. The comparison was made for the first four central moments of the distributions. Dispersions of the normal distribution and distribution of Vavilov turned out to be indistinguishable throughout the entire thickness range.

Z (μm)	0.1	0.5	1.0	1.5	2.0
K	1.8	9.1	18.1	27.3	36.4
A	–0.377	–0.167	–0.115	–0.094	–0.082
$E \cdot 10^3$	–9.28	–8.23	–10.78	–6.35	–5.47

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TOTAL REACTION CROSS SECTIONS OF NEUTRON-RICH LIGHT NUCLEI MEASURED BY THE COMBAS FRAGMENT-SEPARATOR

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Preliminary results of measurements of the total reaction cross sections σ_R for weakly bound ^{4}He, ^{6}He, ^{8}He, ^{7}Li, ^{8}Li, ^{9}Li, ^{11}Li, ^{7}Be, ^{9}Be, ^{10}Be, ^{11}Be, ^{12}Be, ^{8}B, ^{10}B, ^{11}B and ^{12}B nuclei at energy range (10–45) A·MeV with ^{28}Si and ^{181}Ta target are presented. The secondary beams of light nuclei were produced by bombardment of the ^{15}N (50 A·MeV) primary beam on Be target and separated by COMBAS fragment-separator. In dispersive focal plane a horizontal slit defined the momentum acceptance as 1% and a wedge 600 μm degrader of aluminium was installed. The B_ρ of the second section of the fragment-separator was adjusted for measurements in energy range 10÷45 A·MeV. The strong absorption model reproduces the A-dependence of σ_R, but not the detailed structure. We are comparing our experimental data with Glauber multiple scattering theory and preliminary results are obtained.

INVESTIGATION OF $^{14}N+^{10}B$ NUCLEAR REACTIONS OUTPUTS AT LOW ENERGIES

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Angular distributions of elastic scattering of ^{14}N ions by ^{10}B nuclei were measured at the DC-60 cyclotron (Astana, Kazakhstan) at energy E_{lab} (^{14}N) = 21 and 24.5 MeV. At large angles region an anomalous enhancement of cross sections was observed, which is associated with the contribution of the α-cluster transfer process.

The data were analyzed within the coupled-reaction-channel method [1] using FRESCO computer code. In the channel coupling scheme were included elastic scattering and the α-particle transfer reaction. Optical potentials from [2] were taken as the starting ones. In this process, only the depths of the real and imaginary parts of the potential were changed, and only a small correction was made for the radii and diffusions. The cluster transfer mechanism was calculated within DWBA with a finite interaction radius. Here, a prior representation was used. The spectroscopic amplitudes were determined from fitting of the calculated angular distributions to the experimental data.

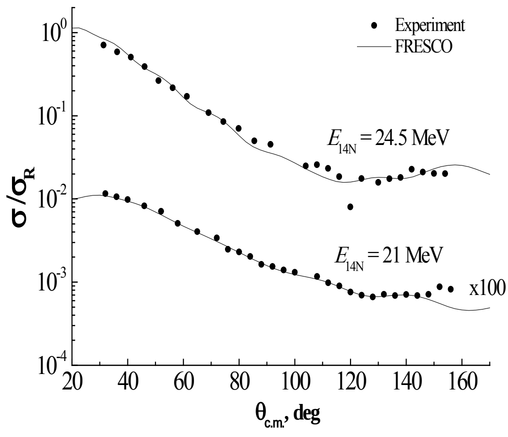

Fig. 1. Comparison of the experimental data (symbols) with the calculated cross sections within the coupled-reaction-channel method using FRESCO computer code.

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KINEMATICAL SIMULATION OF QUASI-FREE SCATTERING OF DEUTERONS AND ALPHA PARTICLES ON CLUSTERS IN ^{6,7}Li AND ^{9}Be

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In present work the method of quasi-free scattering of deuterons and alpha particles on clusters of ^{6,7}Li and ^{9}Be nuclei is proposed to determine the contribution of various cluster configurations in the ^{6}Li (α+d, t+t), ^{7}Li (α+t, t+^{3}He) and ^{9}Be (^{8}Be+n, α+α+n, α+^{5}He) structures. Kinematical simulation of the reactions at E_{lab}(d)= 15 MeV and E_{lab}(α) = 30 MeV was carried out. It is clearly shown that there exist differences in angular and energy distributions of the secondary particles corresponding to specific cluster configurations of nuclei.

The results of simulation show that the obtained data on energy and angular distributions of the secondary particles allow us to make a conclusion about the cluster structure of the ^{6,7}Li and ^{9}Be nuclei.

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EXPERIMENTAL STUDIES OF ϕ-MESON PRODUCTION IN Cu+Au COLLISIONS AT 200 GeV AND U+U COLLISIONS AT 192 GeV

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A major objective in the field of high-energy nuclear physics is to quantify and characterize the quark-gluon plasma (QGP) formed in relativistic heavy-ion collisions, representing an ideal liquid with partonic degrees of freedom [1]. Due to very short lifetime the ϕ-meson provides a key information on the hot and dense medium properties created in the relativistic heavy ion collisions. Since the ϕ-meson is composed of a strange and anti-strange quark, it can be sensitive to the medium-induced effects such as strangeness enhancement, a phenomenon associated with soft particles in bulk matter [2]. The ϕ-meson has a narrow decay width and its peak in the mass spectrum is well separated from the other resonances, thus providing an experimentally clean signal. The PHENIX detector [3] at RHIC [4] provides the capabilities to measure the ϕ-meson production in a wide range of transverse momentum in heavy-ion collisions.

Production of ϕ-mesons in symmetric heavy-ion collisions such as Au+Au, Cu+Cu is well studied [5]. A deeper insight into QGP properties can be gained from asymmetric heavy ion collisions (Cu+Au). In central Cu+Au collision, the smaller nucleus is fully submerged in the larger one thus reducing the contribution of nucleon-nucleon collisions in the low-density nuclear corona region. The principal differences in the geometry of the nuclear overlap region in asymmetric collisions of heavy nuclei are important for systematic study of the parton energy loss, they can help to better constrain input parameters of different theoretical models. Additional insight into the nature of parton energy loss can be gained from U+U interactions since they provide the highest available energy density at RHIC.

In this report we will present invariant transverse momentum spectra and nuclear modification factors of ϕ-meson obtained in Cu+Au collisions at $\sqrt{s_{NN}} = 200$ GeV and U+U collisions at $\sqrt{s_{NN}} = 192$ GeV using the PHENIX detector at RHIC. The results are compared to the ones obtained in symmetric systems as well as to other light mesons (π^0, η) [6].

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EXPERIMENTAL STUDIES OF RESONANCE STATES IN REACTIONS WITH HEAVY IONS ON THE DC-60 CYCLOTRON

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The purpose of the present investigations is to explore the resonances in the nuclei representing astrophysical interest. Studies were carried out by using thick target in inverse kinematics (TTIK) method and time of flight (TF) technique at the Astana cyclotron DC-60 [1–3]. This technique has several advantages such as: to carry out measurements at 180 degrees, to measure excitation functions in a wide energy range, to work near the Coulomb barrier [4–6]. The located below Fig. 1 demonstrates alpha particles from the interaction of ^{16}O with helium. This experiment was carried out to study the compound of the neon nucleus arising in the reaction in the excitation energy range from 6 to 10 MeV. The energy spectrum of this reaction is well known [1] and, therefore, it is possible to compare the results obtained by our method with the classical approach.

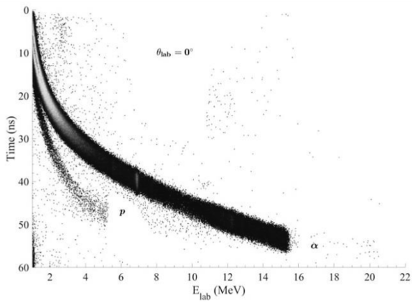

Fig. 1. E-T spectrum for the zero-degree detector, α particles dominate; one can see also a weaker proton locus below the α particles.

Using *R*-matrix approach for the data analysis, the characteristics of the compound nucleus: spin, parity, and the width of the levels can be found [2].

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INVESTIGATION OF THE EXCITATION CROSS SECTION OF ISOMERIC STATES OF ^{143}Sm NUCLEI IN THE REACTIONS (γ,n) AND (n,2n)

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The measurement and interpretation of isomeric ratios have provided information about the energy levels structure of nuclear systems and the angular momentum and reaction mechanism effects involved in the production of isomeric states in nuclei.

In the present work results of investigation of the isomeric yield ratios and cross-section ratios of the (γ,n) and (n,2n) reactions on nuclei ^{144}Sm are presented. The isomeric yield ratios were measured by the induced radioactivity method.

Samples have been irradiated in the bremsstrahlung beam of the betatron in the energy range of 10 ÷ 35 MeV with energy step of 1 MeV. For 14 MeV neutron irradiation we used the NG-150 neutron generator. The gamma spectra reactions products were measured with a spectroscopic system consisting of HPGe detector CANBERRA with energy resolution of 1.8 keV at 1332 keV gamma ray of ^{60}Co, amplifier 2022 and multichannel analyzer 8192 connected to computer for data processing. The filling of the isomeric and ground levels was identified according to their γ lines. In the range 25 ÷ 35 MeV the isomeric yield ratios Y_m/Y_g of the reaction (γ,n) on ^{144}Sm are obtained at first. Using the isomer yield ratio and the total cross section of the (γ, n) reaction on ^{144}Sm [1] we estimated the cross sections of $(\gamma,n)^m$ and $(\gamma,n)^g$ reactions. The cross section isomeric ratios at $E_\gamma=E_m$ are estimated.

The isomeric cross-section ratios σ_m/σ_g was determined in the case of the reaction (n,2n). In order to obtain the absolute values of the cross sections for the ground state and for the isomeric state, use was made of methods based comparing the yields of the reaction under study and the monitoring reaction.

The experimental results have been discussed, compared with those of other authors as well as considered by the statistical model [2]. Theoretical values of the isomeric yield ratios have been calculated by using code TALYS-1.8.

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MEASURING OF BREMSSTRAHLUNG EMISSION IN ALPHA-DECAY OF ^{214}Po

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There are some discrepancis in experimental data of bremsstrahlung emission with energy more than 300 keV in α-decay of ^{210}Po nucleus [1, 2]. Thus, emission probability of γ with about 500 keV in the experiments with scintillator NaI(Tl) detector were obtained as $5\cdot10^{-11}$ keV^{-1}·decay^{-1} [1]. In the other work using HPGe detector the level of $5\cdot10^{-12}$ were achieved for the same energy range. On the other hand there is an interesting agreement between probability of bremsstrahlung emission calculated by single-particle quantum mechanical treatment with rectangular potential with a depth of 10 MeV and Wood-Saxon potential with a depth of 100 MeV.

To establish the reasons of this contradiction an attempt of measuring of bremsstrahlung emission probability at α-decay of nucleus ^{214}Po were produced. The HPGe detector and α-γ coincidence method were used. In order to reduce the effect of random coincidences on the yield of the registered bremsstrahlung photons, the intensity of particles beaming the silicon detector was reduced by an order of magnitude compared to the value given in [2]. Usage of a quick digital oscilloscope also allowed to reduce recorded random coincidence count.

The obtained experimental values of bremsstrahlung probabilities at α-decay were in satisfactory agreement with the results of former experiment [1] and the data of theoretical calculation using realistic nuclear potential [5].

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REGISTRATION OF LOW INTENSIVE α-γ TRANSITIONS IN CHAIN OF Ra-226 DECAY

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The yield of high energy γ-rays from transition of first excited states of nuclei ^{206,210,214}Po and ^{218}Po in chain of ^{226}Ra decay is measured with method α-γ coincidence by means of ultrapure large volume germanium detector. A silicon pin diode with a surface of 1 cm^2 was used as a detector of α-particles and the GS5020 manufactured by «Canberra» with a volume of 100 cm^3 were used as a detector of γ-rays. The α-particle detector and ^{226}Ra source were placed in a vacuum chamber pumped by a turbomolecular pump to a pressure of 10^{-5} mbar. The distance from the detector source was 16 mm. The detector of γ-rays was placed on the outside of the camera behind a thin stainless steel flange at a distance of 35 mm from the source. The angle between the detectors is equal to 90°. The detector signals were registered by a time oscilloscope TDS 7504. The waveforms of coincident events stored in the files were processed off-line using the developed digital algorithms in C++ and Fortran packages [1]. The effectiveness of the registration γ-rays in α-γ-coincidences by germanium detector taking into account the quadrupole nature of their emission were calculated with package Geant-4. From the measured spectra α-γ-coincidence were obtained data of α-decay probability of the isotopes ^{222}Rn, ^{210,214,218}Po on the first excited states of daughter nuclei, followed by removal of excitation by *E*2 transitions with emission γ-quanta with energy of 510, 803.1, 799.7 and 837 keV, respectively.

The obtained experimental values of α-γ_1–transition probabilities were found in satisfactory agreement with the available data in the literature [2] and the results of early experiments [1].

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PROGRAMS OF THE *R*-MATRIX DESCRIPTION OF NEUTRON CROSS SECTION STRUCTURE

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A study of neutron fission and non-fission cross sections performed during many years in the Frank Laboratory of Neutron Physics allowed to accumulate a significant experience in the analysis of resonance structure of the cross section and of correlation effects in fission using a R-matrix formalism. We present a detailed description of the mathematical approach used for the analysis of experimental data with the help of FUMILI minimization in order to extract the parameters of structure of cross section or the correlation coefficients. The following examples are presented: the fits of the total, fission and capture cross sections for ^{235}U in the energy range up to 10 eV, and the fit of the total cross section for ^{181}Ta in the energy range up to 50 eV.

The corresponding codes were written in Fortran, calculations were performed using the FLNP and LIT computer farms at JINR.

MEASUREMENT OF THE (p, *x*p) REACTION CROSS-SECTION FOR PROTON ENERGIES OF 7 MeV ON THE MIDDLE NUCLEI

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At present, the world is searching for alternative ways of developing nuclear power energy, allowing to solve such tasks as increasing the level of safety, reducing the amount of spent nuclear fuel and eliminating the uncontrolled proliferation of nuclear weapons components. The creation of industrial prototypes of hybrid electric-nuclear systems (Accelerator Driven System, ADS), consisting of a deeply subcritical nuclear reactor and a high-energy proton accelerator, allows to solve tasks set.

To correctly model the neutron flux in such devices, data on the spectral composition and angular distributions of secondary protons and light charged particles produced by the primary proton beam in a wide energy range are needed.

The inclusive spectra of protons formed during the interaction of 7 MeV protons on a number of nuclei with $A = 27–120$ were obtained in the isochronous cyclotron U-150M of the Institute of Nuclear Physics (Kazakhstan) in the angular range 15÷135° with a step of 15°.To detect protons, thin silicon detectors 15–25 microns in thickness and a full-absorption silicon detector (1 mm) were used. As a target, self-supporting foils were used, the thickness of which was determined by energy losses of the α particles from the radium source.

An analysis of the experimental results was carried out using the calculation program PRECO-2006 [1], which describes the emission of particles with mass numbers from 1 to 4. A satisfactory agreement between the experimental and calculated values was obtained.

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PROTONS WITH CUMULATIVE VARIABLE *x*>1 MODELLING IN ^{12}C+Be REACTIONS WITH ENERGIES OF 0.6, 0.95 AND 2.0 GeV/NUCLEON

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By the cumulative reaction in this report we mean the production of particles in the kinematic region, which is forbidden by the energy-momentum conservation laws for free nucleon-nucleon collisions.

The FRAGM experiment at the heavy-ion accelerator complex TWAC-ITEP has performed measurements [1] of protons at an angle of 3.5° in C+Be collision at energies of 0.6, 0.95 and 2.0 GeV/nucleon in the Be rest frame.

The invariant proton yields in the cumulative variable range $0.9 < x < 2.4$ were analyzed within the quark cluster fragmentation model [2].

In this report we present invariant proton production cross-sections, simulated using Liege cascade model [3], accordingly to [2]. The results are shown in the Fig. 1. We demonstrate, that in this case [2] proton production in this cumulative region $0.9 < x < 2.4$ can be explained by multiple scattering and processes associated with the formation of nucleon resonances.

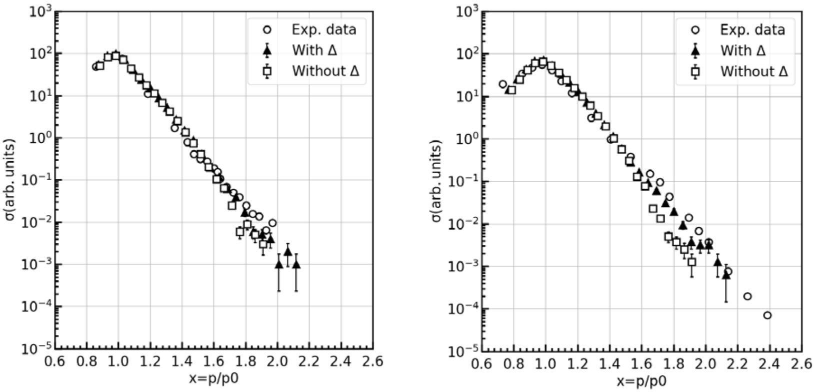

Рис. 1. Proton production cross section (arb. units) in the $^{12}C + {}^{9}Be \rightarrow f + X$ reaction at an angle 3.50 to cumulative variable x at energies 0.6 (left) and 0.95 (right) GeV/nucleon. Experimental data shown by circles [4]. Monte-Carlo simulation without delta production – squares. MC with delta production – triangles.

We acknowledge support from Russian Ministry of Education and Science, state assignment 3.1498.2017/4.6.

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INVESTIGATION OF THE EXCITATION FUNCTIONS FOR (n,p) REACTION ON NUCLEI BETWEEN $40<A<239$

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Nowadays the investigations of the nuclear reactions induced by intermediate energy protons are very important because of wide range of technical applications (production of medical radioisotopes, an estimation of the radiation damage etc.) [1] as well as the fundamental applications (stellar evolution and nucleosynthesis) [2]. Therefore the use of systematics for nuclear reaction cross-section evaluation is very important, if experimental data are absent and results of nuclear model calculation are not reliable. Now we have a lot of semiempirical models for the (n,p) reactions, which can give us cross-section as a function of energy, where Hauser-Feshbach approach was used [3]. For charged particles we have only estimation for energy dependence [4] and recently the analysis from the combination of different models for set of points was obtained [5].

In the present work the excitation functions of proton induced charge exchange reaction were studied. A semiempirical approach for the excitation functions of (p,n) reaction was obtained on the basis of evaporation model with an energy range up to 60 MeV within the nuclide mass region of $40<A<239$. The adjusted parameters of the semiempirical method were investigated. The predictions of the excitation functions for (p,n) reaction for different nuclei are in good agreement with the experimental data.

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INVESTIGATION OF THE ^{179}Hf *K*-ISOMER EXCITATION

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The excitation of the ^{179}Hf *K*-forbidden isomer (I^{π}=25/2^{-}, $T_{1/2}$= 25 days) in the (γ,n)-reaction was investigated by the isomeric ratio method. Targets from natural hafnium were bombarded with gamma-quanta with a boundary energy of 15.1, 17.5, and 37 MeV. The ground state of ^{179}Hf is stable, so the probability of its population was determined from the (γ, n)-reaction at ^{174}Hf. The yields of the (γ, n), (γ, 2n), and (γ, 3n) reactions at ^{174}Hf were taken take into consideration to account for the contribution of the (γ, 3n) reaction from the ^{176}Hf isotope at E_{bound} = 37 MeV. An analysis of the obtained data and the cross-sections of nuclear reactions data made it possible to estimate the background reactions contribution. It was found that the isomeric ratios of the yields are Y_m/Y_g=(6.1±0.3)·10^{-6}; (3.7±0.2)·10^{-6}; (4.4±0.4)·10^{-5} corresponding for gamma-quanta with the boundary energy of 15.1, 17.5, and 37 MeV. The obtained results are discussed.

THE ISOMERIC RATIOS OF THE ^{133,135}Xe YIELD IN THE ^{238}U PHOTOFISSION PRODUCTS

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Investigation of ^{238}U photofission products by bremsstrahlung gamma quanta and determination of isomeric yield ratios for ^{133,135}Xe with I^{π}=9/2^{+} и 1/2^{+} (Y_m/Y_g). The irradiation of the targets was carried out with a M30 microtron. The gamma spectra were measured without radiochemical separation using a Ge-spectrometer with an energy resolution of 1.5 keV on the ^{60}Co gamma line. The obtained data, the boundary energies of the bremsstrahlung gamma quanta and the reactions are shown in the table.

E_{bound} (MeV)	Y_m/Y_g ^{133}Xe	Y_m/Y_g ^{135}Xe	Reactions
6.25	0.08±0.02	0.032±0.005	γ, *f*
12.5	0.26±0.05	0.064±0.008	γ,*f*
14.5	0.16±0.03	0.073±0.008	γ, *f* + γ, n*f*
18	0.46±0.16	0.043±0.006	γ, *f* + γ, n*f* + γ, 2n*f*

f – is the photofission with and without neutron emission

THE INCLUSIVE CROSS SECTIONS FOR THE FORMATION OF p, d, α FROM THE INTERACTION OF α-PARTICLES OF 29 MeV ENERGY WITH NUCLEI ^{27}Al AND ^{59}Co

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Obtaining new experimental nuclear data on double differential and integral cross sections of reactions initiated by stable isotopes of helium aimed at replenishing the information base is necessary for the design of the energy reactor safety systems and the development of promising nuclear technologies.

The experimental spectra of nuclear reactions on the ^{27}Al and ^{59}Co nuclei were obtained on an isochronous cyclotron U-150M (Kazakhstan). The energy of the incident ^{4}He ions was 29 MeV. Measurements are made in the angular range of 30° – 135° in the laboratory coordinate system with a step of 15°. As the target, ^{27}Al and ^{59}Co are selected, as structural elements and elements of the target node of the ADS being designed. Enriched foils of these isotopes were prepared, the thickness and uniformity of which was determined by measuring the energy loss of alpha particles from the ^{226}Ra isotope.

To measure the cross sections of the reactions, a standard *dE-E* method was used, where two parameters of the detected particle are recorded: specific ionization and total energy. The energy calibration of the detectors is based on kinematics calculations within the framework of the LISE code. The analysis of the obtained experimental data is carried out within the framework of the PRECO-2006 [1] design code, which is based on modern theoretical models of nuclear decay.

The obtained experimental results fill the missing values of the cross sections of the reactions studied and can be used in the development of new approaches to the theory of nuclear reactions, as well as in the construction of hybrid nuclear power plants, in nuclear medicine.

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ACTUAL STATUS OF «DANSS» PROJECT

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DANSS [1] spectrometer is a relatively compact (~ 1 m^3) detector of reactor antineutrinos which doesn't contain liquid scintillator, has appropriate Signal-to Background (S/B) ratio and could be moved within few meters from the reactor core. The spectrometer detects about 5000 neutrinos per day and measure their energy spectrum. On-line varying of the core-detector distance within a range from 10.7 to 12.7 m allows us to perform «neutrino diagnostics» of the reactor, namely fuel composition and reactor thermal power. It also lets us to check the «reactor neutrino anomaly» hypothesis – the existence of new «sterile» type of neutrino. Sterile neutrinos are searched for assuming a 4ν model (3 active and 1 sterile ν). The exclusion area in the Δm^2_{14}, $\sin^2(2\theta)_{14}$ plane is calculated using the ratios of positron energy spectra collected at different distances. Therefore results do not depend on the shape and normalization of the reactor $\tilde{\nu}_e$ spectrum and on the detector efficiency.

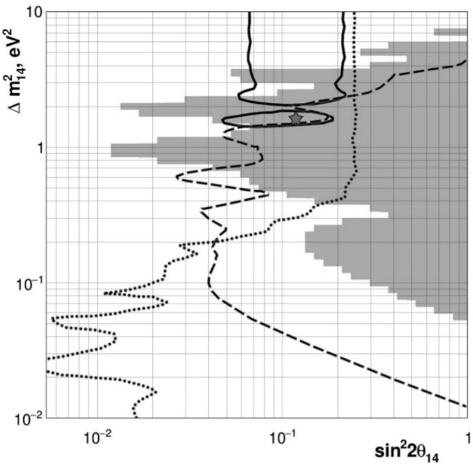

Fig. 1. 90% C.L. exclusion areas in Δm^2_{14} and $\sin^2(2\theta_{14})$ parameter space. Shaded areas are this analysis. Dashed line is the Bugey limit [2]. Dotted line is the Daya Bay limit [3]. Solid line is allowed region from the RAA and GA fit and the star is its best point [4].

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DAMPING PARAMETERS OF THE CHARGE-EXCHANGE GIANT MONOPOLE RESONANCES WITHIN A SEMI-MICROSCOPIC APPROACH

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Proposed recently a semi-microscopic approach [1] is used to evaluate the main damping parameters of the charge-exchange giant monopole resonances in the ^{208,209}Pb parent nuclei. The approach consists in incorporating the "Coulomb description" of isospin-forbidden processes [2, 3] into the newly developed particle-hole dispersive optical model (PHDOM) [4]. The model is a microscopically-based extension of the standard and nonstandard continuum-RPA versions on taking (phenomenologically and in average over the energy) the spreading effect into account. The mentioned giant resonances include the Isobaric Analog Resonance (IAR), its overtone (i.e., the Isovector Giant Monopole Resonance in the $\beta^{(-)}$-channel (IVGMR$^{(-)}$)), the isobaric partner of the IVGMR$^{(-)}$, IVGMR$^{(+)}$. Within the "Coulomb description", the main parameters of IAR damping (partial widths for direct one-proton decay, spreading width, so-called mixing phase) are expressed in terms of the specific charge-exchange Coulomb strength functions taken at the IAR energy (i.e., at the low-energy tail of the IVGMR$^{(-)}$). These strength functions, whose energy dependence exhibit also the maximum corresponding to the respective giant resonance, can be described within the PHDOM (as applied to the Isoscalar Giant Monopole Resonance and its overtone, a similar description is given in Refs. [5]). Being taken at a vicinity of their maxima, these strength functions determine the partial branching ratios for direct one-proton (one-neutron) decay of the IVGMR$^{(-)}$ (IVGMR$^{(+)}$). In evaluation of the above-listed parameters within the used approach, all the model parameters are taken from independent data (including the observed total width of the IVGMR$^{(-)}$). The approach was used in Ref. [1] for a quantitative estimation of the spreading width of the IARs based on the ^{208,209}Pb parent-nuclei ground state. This study is extended in the present work to evaluate all the main parameters of damping the IARs based on the ^{208,209}Pb parent nuclei. The results are compared with the respective experimental data. The calculated branching ratios for one-nucleon direct decay of the IVGMR$^{(\pm)}$ in the ^{208}Pb parent nucleus are also given.

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THE QUARK CONFIGURATIONS AND COLOR SUPERSELECTION RULES

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Symmetric tensor C*-categories due to the algebraic operations as the conjugation, permutation symmetry and composition (separately for morphisms and objects) can be used for building new physical models of quantum systems. In [1] the theory of C*-categories was applied by us to construct an algebraic model with the isospin superselection rules, where the above-mentioned mathematical operations accept a clear physical interpretation (transition to the antiparticle, particle statistics and charge composition). Moreover, morphisms of this category generate the Cuntz algebra as C*-algebra whose G-fixed point subalgebra correspond to the algebra of observables of the system.

In this work, we apply our model to describe the quark configurations at presence color superselection rules. Since the each object of the category represents a certain mathematical structure (hilbert space, representation, endomorphism of the observables algebra etc.), and their entire class correspond to its all possible realizations, the identification of the corresponding morphisms allows to distinguish those structures that correspond to the physically realized configurations of quarks. We built isometric operators that carry superselected charges, which intertwine the vacuum sector with superselection sectors. Projectors, constructed from these isometric operators, are projecting on special subspaces and allow to obtain physically realized “colorless” states. Unitary operators (unitary representations of the permutation group on the Cuntz algebra) corresponding to particle permutations of each sector are also constructed.

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HADRON MASSES AND *NN* POTENTIALS IN THE VACUUM BUBBLE MODEL

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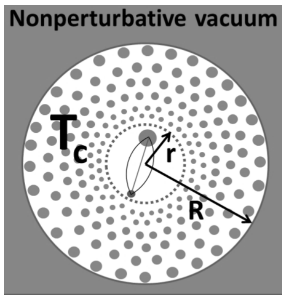
In the Chiral-Invariant Phase Space model [1] the masses of hadrons, consisting of light quarks, have been fitted with accuracy significantly higher than the accuracy of the Quark Bag model. In the Quark Bag Model (an MIT bag) the main parameter is a pressure of the nonperturbative vacuum, which is characterized by a negative energy density, on the perturbative vacuum inside a hadron. The Vacuum Bubble Model (a VNIIA bubble) is a generalization of the Chiral-Invariant Phase Space model for heavy quarks, where the main parameter is a critical temperature T_c of the phase transition between the physical nonperturbative vacuum and the primordial perturbative vacuum inside a hadron. The external radius of the Vacuum Bubble is defined by the critical temperature: $R = \hbar c/T_c$ (about 1 fm). The internal radius of the asymptotically free region r is found to be 0.32 fm. The basic masses of hadrons before the color-electric and the color-magnetic mass shifts are calculated as a root mean square energy of two or three quarks in the thermostat with the local temperature T_c: $M^2 = \Sigma m_i^2 + 2\Sigma_{j>i}(2T_c + x_i)(2T_c + x_j)$, where m_i are quark masses, $x_i = m_i K_0(m_i, R) / K_1(m_i, R)$, $K_0(x)$ and $K_1(x)$ are McDonald's functions.

The masses of the all 93 1*S*-hadrons are calculated with an accuracy of a few MeV. The not yet measured masses of baryons with two or three heavy quarks are predicted. The predicted mass of the Ξ_{cc} baryon is close to the mass of the baryon discovered on LHC in 2017. The Vacuum Bubble model predicts the repulsive core at short distances. At high distances the pseudoscalar π-exchange defines the tensor potential. At middle distances the ω-exchange defines the spin flip potential, and the ρ-exchange defines the spin and the isospin exchange. The scalar part of the potential, which is usually associated with the missing σ-meson, is described by the quark-quark subthreshold exchanges.



A perturbative bubble with valence quarks in the nonperturbative physical vacuum.

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MASS RELATIONS FOR ESTIMATION OF NUCLEON-NUCLEON CORRELATIONS IN NUCLEI

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Estimates of np-pairing magnitude in even nuclei were obtained by use of numerous mass relations [1]. The relations discussed fall in two categories: those based on description of even-odd staggering (EOS) and those treating np-pairs as deutrons. Different mass relations were shown to yield similar results for self-conjugate N=Z nuclei, with $\Delta=24/A^{1/2}$ as an acceptable approximation. These estimates appeared to be greater for self-conjugate N=Z nuclei in comparison to nuclei from other N=Z+const chains (const $\neq$ 0), which may be attributed to symmetry effects in N=Z nuclei [2].

Further analysis revealed that calculations via different relation groups diverge for N=Z+const isotope chains, with EOS based estimates decreasing most drastically. This decrease was shown in part to be a result of different behavior of nucleon separation energies in isotones and isotopes. New formulae were suggested to account for such differences.

Several mass relations were picked as to reproduce the most fitting np-pairing energy values in several chosen nuclei, with ground state multiplet splitting in nuclear spectra as a guide [3]. Cases of nuclei with valence nucleons on $1f_{7/2}$ subshell, as well as a few heavier semimagic nuclei, were observed. It was shown that mass relation

$$\Delta_{np}(N,Z) = B(N,Z) - B(N-1,Z) - B(N,Z-1) + B(N-1,Z-1)$$

demonstrates the best correspondence between pairing effects and GSM splitting in the nuclei handpicked.

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INVESTIGATION OF NEUTRINO PROPERTIES AT KNPP IN GEMMA-III EXPERIMENT

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GEMMA-III experiment is being constructed under the reactor №3 of Kalinin Nuclear Power Plant (KNPP) at a distance of 10 m from the center of the core under an enormous antineutrino flux of more than $5\cdot10^{13}$ ν/(cm^2·s). Such unique conditions allow to investigate fundamental properties of neutrino. In particular, a search of coherent elastic neutrino-nucleus scattering (CENNS) and magnetic moment of neutrino will be performed within the project. A signal from neutrino scattering is detected by low-threshold germanium detectors surrounded by a passive and active shielding reducing the external background in the region of interest down to ~1.0 cts/(keV·kg·day). A special lifting mechanism allows to move the detector away from the reactor core, suppressing main systematic errors caused by possible long-term instability and neutrino flux.

Currently the detector's array consists of four low threshold germanium detectors with a mass of about 400 g each [1]. It was demonstrated a possibility to reach energy threshold of about 350 eV, which is sufficient for search of the coherent neutrino scattering. First CENSS from the reactor would be observed in case of desired background level is achieved. New detectors in GEMMA-III project will have an ultimate resolution of about 80 eV (FWHM) with masses of more than 1 kg each. It would allow to explore an energy region down to about 200 eV and it will greatly increase a sensitivity of the CENNS search. In 2019 new point contact detectors with a total mass of about 5.5 kg will be used for an upgrade of the experimental setup. As a result of the last step the experimental sensitivity for the magnetic moment of neutrino will be improved to the level of $\sim9\cdot10^{-12}$ B after several years of data taking. The setup will open a way to many interesting investigations like search for non-standard neutrino interactions, sterile neutrinos and reactor monitoring. The current status of the experiment will be presented.

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THE NEW TYPES OF GERMANIUM DETECTORS TO SEARCH FOR A NEUTRINOLESS DOUBLE BETA DECAY

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The existence of a neutrinoless double beta decay would prove that the neutrino is a Majorana particle and has a nonzero effective mass. It is also very important that this process is completely forbidden in the Standard Model. Thus, its detection will be equivalent to the discovery of so-called New Physics. At the moment there are many promising experiments to search for a neutrinoless double beta decay, each of them has its own advantages and disadvantages.

Most of contemporary projects are using the active source approach: a detector is made out of isotope-candidate. So far, there is no information about the existence of a neutrinoless double beta decay, but for each isotope, there is a limit on the half-life of this process. Unfortunately, the sensitivities of modern experiments are not sufficient for an unambiguous answer to the question of the hierarchy of neutrino masses, and consequently it is necessary to create new generation experiments that will operate considerably larger masses of isotope candidates for a neutrinoless double beta decay. There is a fundamental necessity to search for some new types of germanium detectors. It is necessary to have a detector that satisfies the following important properties: 1) a significant mass; 2) good spectrometric performance; 3) the ability to operate bare in cryogenic liquid for a long time without deterioration of its characteristics; 4) the possibility to apply the effective pulse shape discrimination methods. Novel point-contact and inverted coaxial germanium detectors are look as promising candidates. Demonstration of the possibility of efficient using the newest types of detectors in liquid argon and/or nitrogen would be a significant step forward in the preparation of the new generation experiment LEGEND [1] to search for a neutrinoless double beta decay.

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NEUTRON STAR MATTER
AND BARYONIC INTERACTIONS

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Neutron stars constitute perfect laboratories to study baryonic matter at densities several times higher than the saturation density of symmetric nuclear matter. Under such extreme conditions hyperons should appear in the baryonic matter, since the nucleon chemical potential becomes large enough to make the conversion of a nucleon into a hyperon energetically favorable [1, 2].

We address the neutron star matter equation of state using nonrelativistic effective potentials in the Skyrme form. This phenomenological approach allows us to study the dependence of the conditions for hyperons appearance in nucleonic matter on the properties of both the hyperon-nucleon and nucleon-nucleon interactions. Earlier, it was shown [3] that the dynamics of hyperon behaviour in neutron-rich systems is determined by the properties of not only ΛN-interaction, but also NN-forces, particularly by the nuclear matter incompressibility. Chemical potentials of hyperons and nucleons are strongly dependent on many-body effects [4], which are suitably incorporated in the Skyrme parametrization as either three-body or density dependent force.

The characteristics of neutron star matter at chemical equilibrium (composition, energy density, pressure, incompressibility, chemical potentials) are calculated and their interrelations with properties of potentials are analyzed.

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ON RESONANT PROPERTIES OF NUCLEAR INTERNAL CONVERSION AND ON POSSIBILITY OF ITS RESONANT STIMULATION

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Nuclear internal conversion (NIC) is the transfer of nuclear excitation energy ΔE to atomic electron and formally is described by the same Feynman diagram as the elastic scattering of two free charged particles. But these processes differ from each other by the character of particles interaction with electromagnetic (EM) field. In the elastic scattering the interchange of energy ΔE between particles in general does not fix the frequency ω of virtual photons and the scattering amplitude depends on intensity $I(\omega)$ of zero-point quantum fluctuations of EM field and photons in the scattering region in wide frequency range, and not only at the transition frequency $\Delta E = \hbar\omega_{res}$.

In contrast, as it is shown in the present work, because only the discrete nuclear energy levels are taking part in NIC and always their half-life $T_{1/2} >> \hbar/\Delta E$, the NIC probability is proportional to the intensity $I(\omega_{res})$ of the EM field modes near resonant frequency ω_{res} only. So, the NIC is stimulated by EM field as in the same fashion that the transition with γ-quantum radiation and for instance in γ-laser the NIC stimulation would compete with the γ-radiation stimulation.

Such resonant NIC character leads to the suppression of low energy NIC inside metallic matrix because the matrix can suppress zero-point EM fluctuations at resonant frequency ω_{res}. In papers [1, 2] by such way was explained the suppression of 76 eV transition in ^{235m}U nuclei inside Ag matrix. In paper [3] there is the overview of the same suppression of 910 eV transition in ^{154m}Eu nuclei and 2.17 keV transition in ^{99m}Tc nuclei inside metallic matrix.

Also the resonant NIC character allows to expect the NIC stimulation when isomeric nuclei are irradiating with resonant photons of ω_{res} frequency. For instance, in paper [4] there was discussed the possibility of increasing the probability of ^{110m}Ag isomer de-excitation in laser plasma by Roentgen radiation which is in resonant with the triggering transition of ΔE = 1128 eV, occurring by inverse internal electron conversion.

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ON STIMULATION OF NUCLEAR ISOMER DE-EXCITATION IN PLASMA OF ELECTRIC EXPLOSION OF CONDUCTORS

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For stimulation of the nuclear isomer de-excitation (NIDE) the most effective mechanism is the stimulation of the triggering nuclear transition of energy ΔE by transferring the energy ΔE to the isomeric nucleus from electronic shell of atom in plasma of temperature $\theta \geq \Delta E$ [1]. The probability P_{NIDE} of NIDE stimulation is proportional to the plasma lifetime τ. In experiment [2] the stimulation of NIDE was found for ^{186m}Re ($T_{1/2} = 2\cdot10^5$ years, $\Delta E \approx 3$ keV) in plasma of $\theta \sim 1$ keV, $\tau \approx 0.3$ ns, which was generated by laser impulses of energy $Q = 300$ J. But NIDE stimulation in Ref. [2] was very weak and for study of the stimulation mechanism there is a need to increase the experimental sensibility by increasing the number N_{is} of isomeric nuclei in plasma, for instance due to expensive increasing of the laser impulse energy Q.

Alternatively it is interesting to consider the expediency of the NIDE stimulation study in the plasma of electric explosion of conductors, where is possible to get $\theta \sim 1$ keV, $\tau \sim 100$ ns at the relatively not rather expensive experimental facility with impulse energy $Q \sim 1$ MJ [3]. Such facility is suitable for study of NIDE stimulation mechanism for ΔE less ~ 1 keV and compared to experiment [2] its sensibility to NIDE stimulation is greater in 6 orders of magnitude due to increasing of P_{NIDE} and N_{is}.

As in experiment [2], the isomer ^{186m}Re is suitable for the study. Another suitable isomer is the ^{110m}Ag ($T_{1/2} = 250$ days, $\Delta E = 1128$ eV). In Ref. [4] there was obtained the estimation of $P_{\mathrm{NIDE}} \sim 10^{-21}$ for ^{110m}Ag de-excitation by inverse internal electron conversion (IIEC) in the plasma of experiment [2]. In this plasma because of small P_{NIDE} and N_{is} values for ^{110m}Ag it is possible to find NIDE stimulation only due to processes more effective than IIEC. But more sensitive experiments with the plasma of electric explosion make possible to find NIDE stimulation of ^{110m}Ag due to IIEC only.

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AB INITIO CALCULATION OF PARTIAL WIDTHS OF NUCLEON RESONANCES OF LIGHT NUCLEI

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A formalism suited to describe nuclear reactions involving resonance single-nucleon states of light nuclei in ab initio calculations using realistic *NN*-potentials is built up. Various bases which include translationally-invariant wave functions of nucleon channels and conventional shell-model functions can be built in the framework of the formalism. We developed a code performing transformations of the channel wave functions to superpositions of ordinary shell-model wave functions. In addition the code allows one to compute one-nucleon spectroscopic factors and form factors of ground and existed states of light nuclei using wave functions obtained in ab initio approaches. So our method may be used to implement fully-microscopic calculations of characteristics of corresponding resonance reactions. The binding energies of weakly-bound states as well as energies and widths of resonance states of ^{5}He, ^{7}Li and ^{9}Be nuclei are computed.

SOFTWARE FOR CALCULATING AND VISUALIZING MASS DIFFERENCE CHARACTERISTICS

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Taking into account pair correlations (in the first approximation describing the residual interaction) allows us to correctly describe the specific properties of the nuclei. Since the first mass characteristics were proposed in the middle of the last century to estimate the effect of nucleon pairing, a large variety of different characteristics arose [1–3]. Despite the simplicity of the formulas of mass ratios, their great diversity, together with the increase in the volume of information on the masses of atomic nuclei, complicates the analysis of the behavior of mass characteristics in nuclear chains (isotopes, isotopes, isobars, nuclei with ($N = Z +$ const). To solve this problem, software was developed that allows calculating and visualizing various mass ratios for estimating the pairing effect of both identical nucleons and np pairs for any chain of nuclei. The program allows to use both the experimental masses [4] and the results of model calculations as input data. The presented software makes it possible to compare the behavior of various characteristics on the whole array of nuclei and to deepen the understanding of the pairing effect. The use of model masses makes it possible, among other things, to determine the correctness of describing the structural effects and effects of pair correlations by this model.

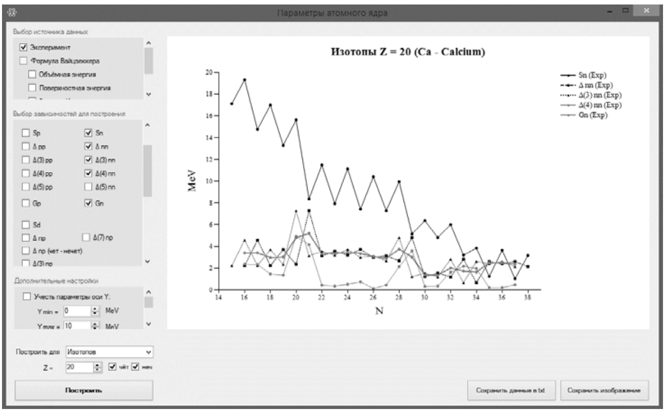

Fig.1. The interface of the program.

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ELECTRONIC CATALOGUE OF MUONIC *X*-RAYS

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μ*X*-ray spectra for *Z* = 9–90 were measured with HPGe detectors and muonic beams of PSI (Villigen, Switzerland) [1] for the period from 1996 to 2006. The results are presented as electronic atlas composed of graphic plots. The atlas is available at JINR site Ref. [2]. As an example, Fig. 1 presents the energy spectrum of μ*X*-rays in cadmium target.

The information from the μ*X*-ray spectra catalogue could be useful for the identification of the background structure and for the correct selection of the targets and constructive materials for different experiments with muons.

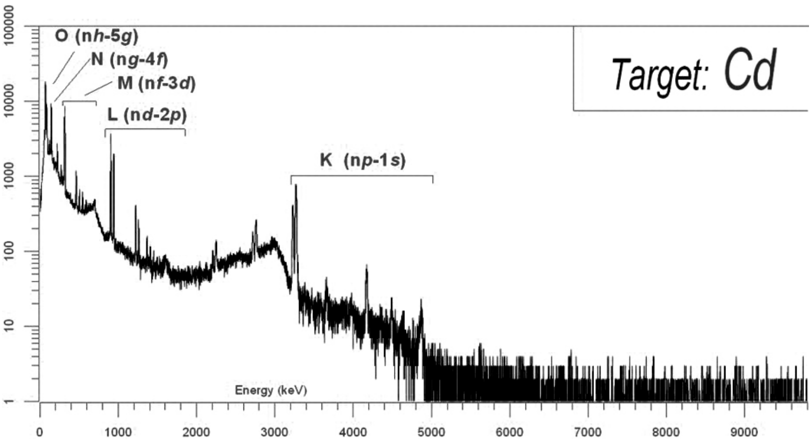

Fig. 1. Total muonic X-ray spectrum of Cd.

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PAIRING ENERGIES VIA NEUTRON EXCESS FOR 150≤ A ≤190

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Increasing neutron excess, $I=(N-Z)/A$, leads to the deepening of the proton mean potential and, thereby, to the reduction of the proton distribution radius [1]. The same reason gives, on the contrary, increasing neutron radius at the growth of I. Thus, an average value of matrix elements of the short-range force in the particle-particle channel (that can be reduced to the effective monopole pairing strength G_τ, τ = n, p) increases for protons and decreases for neutrons. Simultaneously the average level density (ρ_τ) changes in accordance with the distribution radius (e.g. the proton density, ρ_p, decreases). Therefore the pairing gap Δ_τ, which is $\sim\exp[-1/(G\rho)_\tau]$ in the Bardeen-Cooper-Schrieffer theory, decreases mainly with I^2 [2]. Besides Δ_τ is affected by local fluctuation of ρ_τ.

The pairing energies P_τ (which are obtained from mass differences), have the same dependences as Δ_τ but in addition the blocking effect and quasiparticle-phonon interaction can make $P_\tau \neq \Delta_\tau$. All these factors result in a large scattering of P_τ. So at ΔA = 2 and practically at the same I sometimes P_τ can differ by ~0.5 MeV.

Nevertheless, P_τ for the fixed quantum states [3] in the mass region of deformed nuclei 150≤ A ≤190 reveals an explicit tendency to diminution with increase of I that is displayed by average values of $(P_\tau A^{1/3})_{av}$, given in Table.

I	neutrons, τ = n			protons, τ = p		
	0.162	0.183	0.203	0.163	0.181	0.201
$(P_\tau A^{1/3})_{av}$, MeV	5.01	4.18	3.30	5.08	4.38	3.93

As mentioned above and in accordance with [4] P_τ are described by $P_\tau = A^{-1/3} a_{0\tau}\left(1 - a_{2\tau} I^2\right)$. Parameters $a_{0\tau}$ and $a_{2\tau}$ are selected for $(P_\tau A^{1/3})_{av}$: a_{0n} = a_{0p} = 7.98 ≈ 8.0 MeV; a_{2n} = –14.25; a_{2p} = –13.77. $a_{2\tau}$ are practically identical for neutrons and protons and essentially more than in [4] where $a_{2n} = a_{2p} = 2$. Since in [4] Δ_τ and P_τ are calculated by the Hartree-Fock-Bogolubov method with realistic forces fixed for stable spherical nuclei, our results, which testifies to a considerable recession of $P_\tau A^{1/3}$ with the growth of I, possibly accumulates the change of deformations.

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(J–1) ANOMALY AND PAIRING ENERGY

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Two different cases of the (j–1)-anomaly are considered. If protons occupy the intruder level $1g\,9/2$ the anomaly takes place. So in $_{47}Ag_{56}$ the ground state has spin $7/2^{+}$ ($g\,9/2$ + a quadrupole phonon) whereas level $9/2^{+}$ is higher by ~13 keV. In odd Ag isotopes with $A > 103$ level $7/2^{+}$ is an excited state (25÷70 keV) nonetheless state $9/2^{+}$ is higher by ~50 keV. At the same time the inversion of level $11/2^{-}$ ($1h\,11/2$) and $9/2^{-}$ is noticeable in one odd barium (Z=56, N=75) in which these levels are observed as excited states (~90 keV) with 80 keV energy difference between $9/2$ and $11/2$ levels. Such distinction can be mainly accounted for by distinguishing single-particle spectra for protons at $40 < Z < 50$ and for neutrons at $64 < N < 82$. In the first case proton level $1g\,9/2$ is separated from the f–p shell by an energy spacing of ~1.7 MeV, whilst level $1h\,11/2$ is beneath levels $3s\,1/2$ and $2d\,3/2$ only by ~10 keV and ~30 keV respectively. However, in these two (j–1)-anomalies the structure of the low-lying quadrupole phonon which brings about lowering the (j–1)-level [1] comprises a considerable component of an appropriate two-qusiparticle configuration: in Pd (Z=46, N=56) and Cd (Z=48, N=56) two-proton configuration $(1g\,9/2)^2$ amounts to ~30% and ~15% respectively and in Ba (Z=56, N=74,76) two-neutron one $(1h\,11/2)^2$ gives ~25%. The phonon structure is calculated by the method given in [2].

A substantial phonon admixture in the wave function of an odd nucleus reveals itself in the pairing energy $P_\tau(\tau = \mathrm{p,n})$ by means of two effects: first, owing to a lowering state energy in the odd nucleus (that reduces P_τ) and, secondly, by the blocking effects because of the presence of the phonon (P_τ increases at the complete blocking that leads to disappearance of the nuclear superfluidity in odd nuclei). In the investigated cases the pairing energies [3] are somewhat higher than the average values: P_p (Z=45, 47; A=101÷111) ≥ 1.50 MeV, P_p(aver.) ≈ 1.2 MeV; P_n(N=75; A≈130) ≥ 1.25 MeV, P_n (aver.) ≈ 1.0 MeV. Thus, the blocking effects predominates.

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NEUTRINO INTERACTION WITH ATOMIC NUCLEI

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Neutrino-nucleus interaction, which has many applications, such as neutrino detection, neutrino oscillations study, nucleosynthesis processes examination is considered. Appropriate cross sections values depend on nuclear matrix elements, which are the goal of calculations for a variety of nuclear models. For there is a certain spread of results of these estimations it is reasonable to obtain nuclear matrix elements by the model-independent approach, which use experimental data on nuclear reactions. These are beta decay processes, charge exchange reactions, nuclear resonance fluorescence, which can give direct information on nuclear structure. The corresponding model-independent cross section calculations are produced and compared with existing experimental data on neutrino-nucleus interaction.

SUPPRESSION OF WEAK FORCES IN NUCLEI

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On the basis of dynamic collective model (DCM) [1] we have elaborated the method for calculation of the reduced probabilities of beta transitions to the excited states of odd nuclei with the account of quasiparticle and multiphonon (up to 10 phonons) states and vacuum fluctuations of quasiparticles [2]. Renormalization of weak interaction constants for nuclei from area A = 100, defined in work [2] from systematization of experimental data, has been taken as a base of studying of the role of structural effects on β decay of odd nuclei within the limits of DCM. It was thus far supposed, that it is caused by influence of Fermi and Gamow-Teller resonances, therefore can be different for various nuclei due to strong distinction of Fermi surfaces in them.

However, the calculations carried out for nuclei with 31 < A < 231 have shown, that in cases of good description of spectrum and spectroscopic characteristics of daughter nuclei a good description of the probability of nuclei β-decay is obtained in a wide mass region and the spectrum of the excited states with a universal value of the renormalization constants of the weak interaction

$$[g_A/g_V]_{\text{exp}} = 0.343[g_A/g_V]_{\text{free}}$$

This means that the observed in the experiment the suppression of the probability of nuclei β-decay is determined by an adequate description of structure of wave functions and some universal suppression mechanism of the weak force, not depending on the mass number nor the energy excited in the β-decay of states.

Of course, Fermi- and Gamow-Teller resonances play a role in the observed suppression of the probability of nuclei β-decay, but at the level of amendments 0.1–0.3 in value log*ft*.

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PROPERTIES OF HEAVY AND SUPER-HEAVY NUCLEI WITH *N* = 149, 151, AND 153

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Experimental spectroscopic data on nuclear structure of heavy and super-heavy nuclei still require adequate theoretical descriptions. The work is devoted to the description of quasi-neutron structure of odd isotones in chain with $N = 149$, 151, and 153: ^{243,245,247}Pu, ^{245,247,249}Cm, ^{247,249,251}Cf, ^{249,251,253}Fm, ^{251,253,255}No, and ^{253,255,257}Rf. The nuclei in question were presented by the combination of a valent neutron and a solid deformed even-even core in order to take the Coriolis interaction into account [1]. Minimization of potential surface with respect to collective parameters was carried out states in the frame of two center shell model (TCSHM) [2]. Deformations of the ground states and corresponding low lying quasi-neutron states were calculated. The blocking effect was taken into account. Transition probabilities and lifetimes for low lying quasi-neutron states were estimated and compared with experimental data. According to the experimental data some levels in nuclei from the considered isotonic chains reveal an isomeric behavior [3] with a large half-life from μs to sec [4]. This behavior was analyzed in our calculations. Particular attention was payed to the sensitivity of obtained results on model parameters.

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SEARCH FOR PERIODICAL VARIATIONS OF Fe-55 ISOTOP WEAK DECAY PARAMETERS

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Possible temporal variations of nucleus decay parameters studied extensively in the last years, their observation can be the signal of unknown physical effects. Earlier, several experiments reported the annual and daily decay rate oscillations in alpha and beta-decays of some nuclides on the order of 0.05% [1, 2]. Our experiment studies the decay rate variations in inverse beta-decay (*e*-capture) of Fe-55 isotope. In this process *K*-shell electron absorbed by nuclei and electron neutrino emitted; it accompanied by *X*-ray with energy 5.9 or 6.4 keV which in our set-up detected by cooled Si-Pin detectors. Measurements of decay rate performed in 2016–2018, demonstrate that together with observed Fe-55 decay exponent with life-time 1004 days, annual oscillation component value is present at the level (0.21 ± 0.04)%. Another period 29.5 ± 1.5 days corresponding to moon month is found with amplitude (0.32 ± 0.4)%.

Analogous Fe-55 decay measurements by Si-Pin detectors in orbital flight conditions are planned at International Space Station as part of DODO project.

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NEW RESULTS OF THE SEARCH FOR NEUTRINOLESS DOUBLE BETA DECAY FROM GERDA PHASE II

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The GERDA (GERmanium Detector Array) experiment [1], located at the Gran Sasso National underground laboratory in Italy, is one of the leading experiments for the search of 0νββ decay. GERDA operates with bare semiconductor detectors made of germanium with an enriched Ge-76 fraction in liquid argon. In Phase II of the experiment, 35.6 kg of enriched germanium detectors are used. The application of active background rejection methods, such as a liquid argon scintillation light read-out and pulse shape discrimination of detector signals, allowed to reduce the background index to the intended level of 10^{-3} cts/(keV·kg·yr). At the time of the conference the new results based on the analysis of more than 2 years of data taking in Phase II are going to be presented. So far the GERDA half-life sensitivity for 0νββ decay is one of the best amongst all competitors.

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SOLAR NEUTRINO CAPTURE CROSS-SECTION FOR ^{76}Ge NUCLEI

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In GERDA and LEGEND experiments for double beta-decay investigation, the total energy of beta electrons is measured. The absorption of solar neutrino by the ^{76}Ge isotope in the $^{76}Ge(\nu_e,e)^{76}As$ reaction induces a background event which is indistinguishable from the beta decay signal.

We estimate the cross sections for solar neutrino capture by ^{76}Ge nucleus for various excited states of the daughter nucleus of ^{76}As. The Gamow-Teller transitions to the low-lying excited states and the Fermi transitions to the resonance states of this nucleus were taken into account. The applied calculation technique was based on [1, 2]. The experimental data for matrix elements from charge-exchange reactions [3] and theoretical Fermi functions [4] were used in the calculations. The total number of neutrino events was calculated by convolving the obtained cross sections with the spectrum of solar neutrinos. The spectrum of solar neutrinos was taken from the model BS05 (OP) [5].

For known excited nucleus levels of ^{76}As with an energy of less than 5 MeV, the solar neutrino event frequency is equal to 15.9 SNU. This practically coincided with the results of [1] (15.6 SNU). The effect of resonant excitations, including giant Gamow-Teller and isobaric analog resonances, is considered. We demonstrate that these resonant excitations could not be neglected for calculating the interaction cross-section of neutrinos with the ^{76}Ge isotope.

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THE SPECTRUM OF UNSTABLE ISOTOPES ^{9}He AND ^{10}He

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The unbound nuclear system of ^{10}He has been studied many times both theoretically and experimentally. However, controversy in experimental results still exists. One can divide all obtained experimental results in two groups. The first one is population of ^{10}He in reactions with halo-nuclei. In particular, the ^{10}He was first time experimentally observed in 1994 in reaction of proton knockout from ^{11}Li [1]. A wide peak at energy about 1.2 MeV was observed in the experiment. Therefore, the decay energy of ^{10}He ground state 1.2 MeV was assigned. Such ^{10}He ground state prescription was confirmed in further experiments with beams of ^{11}Li and ^{14}Be. The second group of data is a population of ^{10}He in two-neutron transfer reaction. In an experiment conducted in FLNR at JINR the ^{3}H(^{8}He,p)^{10}He reaction was used to populate ^{10}He [2]. The obtained spectrum shows significantly different behavior: peak at decay energy about 1.2 MeV was not observed. Further analysis of inclusive spectrum in combination with correlation studies provided the decay energy of ^{10}He ground state at about 2.1 MeV.

We propose theoretical interpretation that explains behavior of all obtained experimental data and thus reconcile experimental situation [3]. The difference in the ^{10}He spectrum behavior can be explained by influence of initial state structure.

The properties of ^{10}He continuum are closely connected with properties of ^{9}He continuum. Existing experimental data about ^{9}He and the limitation on properties of ^{9}He states connected with the observed ^{10}He spectrum are also discussed.

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BYUON ENERGY: DARK ENERGY, COSMIC RAYS UP TO ULTRAHIGH ENERGY, GAMMA-RAY BURSTS, RESULTS OF TERRESTRIAL EXPERIMENTS

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The Theory of byuon (TB) is a non-gauge theory of the formation of physical space and the world of ultimate particles on the basis of unobservable objects named "byuons" which containing a new fundamental vector constant – cosmologic vector potential A_g is showed in [1]. It was shown in [1] that ultimate particle mass ($\Delta mc^2 \approx 33$ eV) is in party proportional to the modulus of summary potential A_Σ ($A_\Sigma \leq A_g = 1.95\cdot10^{11}$ G·cm). Decreasing in the modulus (ΔA_Σ) of due to other field potentials should lead to the emergence of new non gauge natural force that is nonlinear and nonlocal and can be represented by a series in terms of ΔA_Σ and new byuon energy.

The new interaction explains the origin of dark energy as a cause of receding galaxies with acceleration (byuon energy). The author has developed this mechanism for accelerating of cosmic rays (CRs) with the application of the new force theory too. It was shown that CR can reach energy exceeding the Greisen-Zatsepin-Kuzmin limit of $5\cdot10^{19}$ eV. The basic problems of gamma-rays bursts nature can be solved in the framework of TB not only for bursts connected with supernova explosions but also for those without explosions [2].

In this report we shall discuss the experiments with heat installations too which use byuon energy for heat of the water. The experiments were carried out in Italy (2012–2014) and Russia (2015–2017). For realization the new force action (ΔA_Σ) we used a gravitation potential. The heat generation is produced in a vertically-shaped closed water circuit using an electric pump. Our experiments shown that coefficient K (the ratio between the heat energy output and the electric energy input) can be more 1. Coefficient K is increased with increasing of installation height. We introduced a sections and an effective height for our installation. The effective height is equal to the height of one section multiplied on the sections quantity. Therefore we can get any *K* values (2, 3, 4 etc.).

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NUCLEAR REACTIONS WITH NEUTRONS IN ENVELOPES OF ACCRETING NEUTRON STARS

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I discuss nuclear reactions with neutrons in the envelopes of accreting neutron stars. I show that some of such reactions was overlooked in previous studies (see e.g. the most recent one [1] and references therein) and analyze their effect on envelope composition and heat realize in the envelope of accreting neutron stars. In particular, I demonstrate that strong neutrino cooling by cycles of electron capture and β-decay, allowed for specific pairs of nuclei in neutron star envelope [2], is drastically suppressed due to burning out of the nuclei, participating in the most powerful of such cycles. The results are important for proper interpretation of observation of transiently accreting neutron stars.

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DESCRIPTION OF BANDCROSSING OF Ba ISOTOPES BY MICROSCOPIC VERSION OF IBM1

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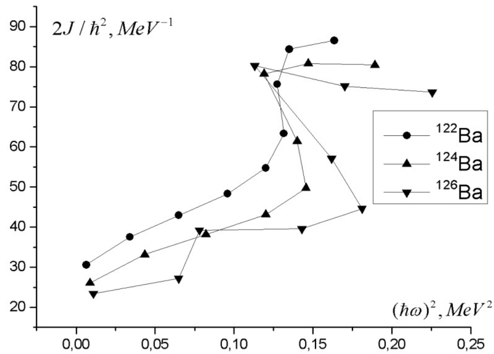
The microscopic version of the Interaction Boson Model 1 (IBM1), which uses only one quadrupole boson d_μ, is presented in general outline in [1]. In it parameters of the IBM1 Hamiltonian and *E2*-operator are calculated by means of the most collective lowlying quadrupole phonon D_μ and a wide spectrum of positive parity phonons with spin $\lambda \le 6$ which renormalize the IBM1 parameters. For description of the bandcrossing bosons with $\lambda = 8, 10$ are immediately included in boson wave functions and the interaction of these bosons with d_μ-bosons are found microscopically.

Effective moment of inertia J via rotation frequency squared $(\hbar\omega)^2$, gives a very clear picture of the band-crossing character. Fig. displays that bandcrossing as backbending reveal itself for Ba isotopes at $(\hbar\omega)^2 = 0.15$, i.e. for the state with spin $I = 12$. With the growth of mass number the backbending becomes sharper. Fig. is constructed with experimental energies with which theoretical ones are in satisfactory agreements. Explanation of phenomena in Fig. consists in that, with increasing A (from 122 to 126) the neutron chemical potential approaches to level $h_{11/2}$ and just two quasiparticles on $h_{11/2}$ give phonons with $\lambda = 8, 10$ and the phonon energies lower beneath the energies of pure collective states. This is confirmed by boson wave function: in ^{126}Ba for states with $I \le 10$ boson with $\lambda = 10$ is practically absent, in state $I = 12$ its part is $\sim 55\%$ and for states with $I > 12$ is more then 95%. Thereby for ^{126}Ba the theoretical value of $B(E2; 12^+ \to 10^+)$ is two times less than for transition $10^+ \to 8^+$ and then $B(E2)$ increase that coincides in fact with experimental date.



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SPLINE APPROXIMATION METHOD FOR SOLVING HYPERRADIAL EQUATIONS FOR 3- AND 4-BODY SYSTEMS

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New effective method for solving of the system of hyperradial equations [1] is proposed. The idea of this method is simultaneous calculation of the mesh function and its second derivative using the cubic spline interpolation expression [2]. As a result, the solving of the system of hyperradial equations is reduced to the eigenvalue problem of some matrix *B* [3]. The main advantage of this method is the smooth interpolation between the mesh points. For the equidistant mesh, the matrix *B* is symmetric, but size of the matrix *B* may be large. For a special choice of the non-uniform mesh, the size of the asymmetric matrix *B* may be small and calculations (only for the ground state) may be fast. The proposed method was tested for 3- and 4-body oscillatory systems as well as ^{3}H, ^{3,4,6}He, ^{6,7}Li, ^{12}C, and ^{16}O nuclei. The nuclei ^{3}H and ^{3,4}He were considered as consisting of protons and neutrons, whereas the nuclei ^{6}He, ^{6}Li, ^{12}C, and ^{16}O were considered as α-cluster nuclei. The agreement with the experimental data on the binding energies was obtained using the effective nucleon-nucleon interaction potentials similar to the M3Y potential. The convergence of the proposed algorithm is shown in Fig. 1.

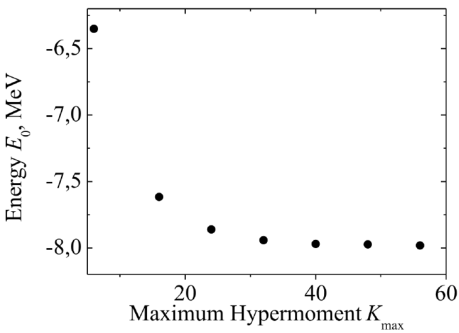

Fig. 1. Convergence of the proposed algorithm for the exactly solvable 3-body model with M3Y nuclear interaction and the exact value of the ground state energy $E_0 = -8$ MeV.

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ASTROPHYSICAL *S*-FACTOR OF THE DIRECT α(d,γ)^{6}Li CAPTURE REACTION IN A THREE-BODY MODEL

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Astrophysical *S*-factor of the direct α(d,γ)^{6}Li capture reaction is evaluated in a three-body model [1, 2]. The final ^{6}Li nucleus is described as a bound state of α+p+n in the Hyperspherical Lagrange mesh method. At the long-wavelength approximation, *E*1 transitions are forbidden between isospin-zero states. Hence *E*1 radiative capture is strongly hindered in reactions involving $N = Z$ nuclei but the *E*1 astrophysical *S*-factor may remain comparable to, or larger than, the *E*2 one. It is shown that the theoretical estimation for the isovector *E*1 capture due to the small isovector component of the final ^{6}Li nucleus with a norm square of order 10^{-3} is dominant at low astrophysical energies. The *E*2 *S*-factor is estimated with the three body wave function with corrected asymptotics at a distance of 5–10 fm.

The astrophysical *S* factor computed in a three-body α + n + p model is in a very good agreement with the recent low-energy experimental data of the LUNA collaboration [3] (see Fig. 1). This confirms that a correct treatment of the isovector *E*1 transitions involving small isospin-one admixtures in the wave functions should be able to provide an explanation of the data without adjustable parameter. The exact-masses prescription which is often used to avoid the disappearance of the *E*1 matrix element in potential models is not founded at the microscopic level and should not be used for such reactions [2].

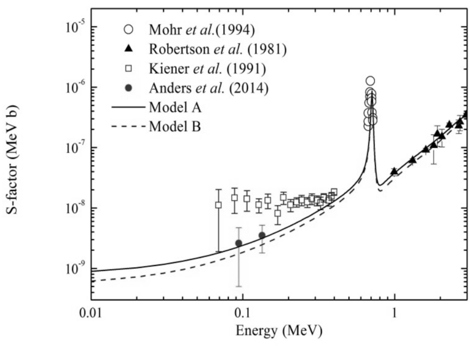

Fig. 1. Astrophysical S factor within the three-body model in comparison with experimental data. Model A(B) is based on the Kukulin et al. (Kanada et al.) αN- potential.

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EXCITATION OF NUCLEAR ISOMERIC STATES IN FIELD OF SYNCHROTRON RADIATION

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We calculated the probabilities of excitation of nuclear isomeric states in nuclei with two low-laying excited states by synchrotron radiation (SR). The lower one is an isomeric state having the energy of E^*, and the total spin of J^*. The higher one is an excited state with the energy less than 250 keV. Besides, the total spin (J) of this state is such that the electromagnetic transitions of low multipolarities into the ground state and into the isomeric state of a nucleus are allowed.

In our calculations, we used a radiation from the synchrotron of the third generation (Spring-8, Japan) [1]. This synchrotron produces electromagnetic waves with the photon energies up to 300 keV. Such radiant energy range assumes a research of the direct effect of the radiation onto characteristics of the nuclear states. In addition, the synchrotrons of the third generation produce a high-intensity radiation of the frequency continuous spectrum (from a wiggler).

Our model includes resonant transition from the ground state of the nucleus into the second excited state and then the natural electromagnetic transition from this state into the isomeric one. This transition involves a spontaneous component and an induced component. The time dynamics of the energy level population in a SR field is estimated from the set of kinetic equations. We investigated several nuclei with the reliable values of the experimental characteristics. These are ^{169}Lu, ^{171}Lu, and ^{191}Os isotopes. The rates of the excitation processes of the nuclear isomeric states were calculated by using the well-known form of the SR spectra of the Spring-8 synchrotron (from the wiggler) [1]. We estimated the quantities of nuclear matrix elements of the gamma transitions using the Nilsson model.

The following quantities of nucleus yields in the isomeric states are obtained: $5.2\cdot10^5\ s^{-1}$ for ^{169}Lu isotope, $4.6\cdot10^7\ s^{-1}$ for ^{171}Lu isotope, and $5.6\cdot10^4\ s^{-1}$ for ^{191}Os isotope. Quantities of these yields calculated with the use of the Weisskopf approximate formulae for the nuclear matrix elements of gamma transitions are 2–3 times less.

1. http://www.spring8.or.jp

CROSS-SECTIONS FOR THE SOLAR NEUTRINOS CAPTURE BY NUCLEI AND CHARGE-EXCHANGE RESONANCES

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Investigation of the resonance structure of strength functions is an important task for calculating the cross sections of the back beta-decay reactions that can be used in neutrino detectors.

In the resonance structure of the strength function, analog resonance, Gamow-Teller resonance (GTR) [1] and three pigmy resonances (PRi) are selected [2]. Even when the two resonances of GTP and PR1 are not taken into account in the $^{71}Ga(\nu_e,e^-)^{71}Ge$ reaction, the neutrino capture cross section σ(*E*) decreases from ~20% to ~60% with the neutrino energy in the interval 2–12 MeV [3]. Only not accounting the GTR gives a decrease in the σ(*E*) value in this reaction by 25% even at E_ν = 4 MeV. In the $^{98}Mo(\nu_e,e^-)^{98}Tc$ reaction, not taking into account two resonances, the GTR and PR1 reduces the cross section σ(*E*) from ~ 6% to ~ 60% with a change the neutrino energy in the interval 4–14 MeV, and not taking into account only the GTR, the σ(*E*) value decreases by 16% at E_ν = 6 MeV and by 45% at E_ν = 14 MeV. In the $^{127}I(\nu_e,e^-)^{127}Xe$ reaction, not taking into account two resonances, the GTR and PR1 reduces the cross section σ(*E*) by a value from ~ 25% to ~ 80% with the neutrino energy in the interval 2–12 MeV and not taking into account only the GTR, the cross section σ(*E*) decreases by 19% at E_ν = 2 MeV and by 69% at E_ν = 14 MeV.

The number of events in the interaction of solar neutrinos with these nuclei is given in the table. All values are given in the SNU. The spectrum of solar neutrinos is taken from model B16-AGSS09met [4].

	B	pp	hep	^{13}N	^{15}O	^{17}F	total
^{71}Ga	11.885	1.505	0.09	0.335	0.666	0.152	14.496
^{98}Mo	11.826		0.093				11.919
^{127}I	10.166		0.084	0.024	0.109	0.00247	10.386

It can be seen from the table that boron neutrinos with energies up to 16.36 MeV (E_{max} = 6.44 MeV) make the main contribution and it is important to take into account all the resonances.

This work was supported in part by the Russian Foundation for Basic Research (project 18-02-00670).

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CALCULATION OF *Eλ*-TRANSITIONS IN HEAVY NUCLEI

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In Ref. [1] the spectra of non-rotational states as well as the structure of these states have been studied in the nuclei of isotonic chains of heavy nuclei based on the microscopic-macroscopic approach and Quasiparticle-Phonon Model [2, 3].

Using the same theoretical formalism, in the present work we consider the decay characteristics of heavy nuclei. The calculated reduced probabilities $B(E\lambda(M\lambda), I^{\pi}K(K{=}\mu) \rightarrow 0^{+}0)$ of electromagnetic transitions from the vibrational quadrupole or octupole states into the ground state and the energies Q_{α} of alpha-decay are compared with the available experimental data. The calculation does not contain any free parameters. In Table 1, the part of the results obtained is presented for nuclei ^{246}Cm and ^{250}Cf.

$I^{\pi}K(\lambda\mu)$	$E_{\lambda\mu}$ [keV] exp.	$E_{\lambda\mu}$ [keV] theor.	$B(E\lambda, I^{\pi}K \rightarrow 0^{+}0)$ [$e^2fm^{2\lambda}$] exp.	$B(E\lambda, I^{\pi}K \rightarrow 0^{+}0)$ [$e^2fm^{2\lambda}$] theor.
^{246}Cm(exp.[4]):				
2^{+} 0(20)	1175	1200	–	60
2^{+} 2(22)	1124	1300	448	310
3^{-} 0(30)	1250	1300	$4.76 \cdot 10^4$	$3 \cdot 10^4$
3^{-} 1(31)	1079	1000	–	$2 \cdot 10^4$
3^{-} 2(32)	842	900	$3.80 \cdot 10^4$	$3 \cdot 10^4$
3^{-} 3(33)	–	1400	–	$2 \cdot 10^4$
^{250}Cf(exp.[5]):				
2^{+} 0(20)	1154	1200	–	120
2^{+} 2(22)	1032	1300	215	240
3^{-} 0(30)	1335	1300	$6.57 \cdot 10^3$	$1.8 \cdot 10^4$
3^{-} 1(31)	1176	1000	$2.76 \cdot 10^4$	$2.7 \cdot 10^4$
3^{-} 2(32)	872	900	$2.89 \cdot 10^4$	$2.3 \cdot 10^4$
3^{-} 3(33)	1427	1400	$1.90 \cdot 10^4$	$1.5 \cdot 10^4$

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SUPERALGEBRAIC FORM OF THE DIRAC EQUATION

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The method of secondary quantization for fermion systems was proposed in 1928 by Wigner and Jordan [1] and modified in 1934 by Heisenberg [2]. The modern formulation of the method of second quantization, based on the superalgebraic approach, is given in Berezin's paper [3], and the mathematical apparatus of the method is developed in [4].

In nuclear physics, the secondary quantization apparatus is important when considering high-energy processes accompanied by the production of nucleon-antinucleon pairs, the study of spin-isospin sound in nucleon matter, calculations of form factors in nuclear shell models, etc.

In [5, 6] the author proposed an approach in which a superalgebraic representation of not only spinors is used, as in the works of Berezin, but also of Dirac matrices. This approach extends the theory of algebraic spinors and allows us to give a unified algebraic interpretation of the spinors and Dirac matrices. In [7], within the framework of the superalgebraic approach, the principles of the Lorentz transformations and Lorentz-covariance for fermion fields are formulated, and the foundations of the superalgebraic theory of the second quantization of fermion fields are constructed.

This paper develops the approach proposed by the author in [5–7]. A superalgebraic representation of the spinors and Dirac matrices is used. On this basis, a theory of spinors is constructed, in which there is no need to use the normalization of operators, and which is automatically Lorentz-covariant and secondarily quantized. The creation-annihilation operators of spinors are constructed using integrals of the densities of Grassmann variables in momentum space and derivatives with respect to them. The properties of solutions of the superalgebraic Dirac equation are considered in detail. Formulas for superalgebraic bilinear covariants, Lagrangian of the fermion field, and Noether conserved currents are derived.

The developed theory simplifies the use of the formulas of the theory of second quantization and avoids a number of problems related to divergences.

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THE LEPTON CHARGES IN THE PATTERN OF CURRENTS DESCRIPTIONS OF THE WEAK PROCESSES

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A development [1], the predictions of the lepton quantum number (charge) conservation laws about processes simultaneously involving leptons of the first two generations are considered.

1) The description of the lepton families by including “charge” quantum number l_{ch}, equal to +1 for e^-, μ^-, τ^-, and -1 for e^+, μ^+, τ^+ with conserving its sum L_{ch} and “neutral” l_ν, equal to +1 for ν_e, ν_μ, ν_τ, and -1 for $\tilde{\nu}_e, \tilde{\nu}_\mu, \tilde{\nu}_\tau$ with conserving the total flavor L_ν is introduced.

In the framework of this scheme with left-handed neutral leptons, the processes caused by interaction of the nondiagonal neutral currents and by its interactions with the diagonal partners, in particular, the $(\nu_e \leftrightarrow \nu_\mu)$ and $(\tilde{\nu}_e \leftrightarrow \tilde{\nu}_\mu)$ conversions as well as the decay mode $\mu^- \to e^- \nu_\mu \tilde{\nu}_e$ are predicted.

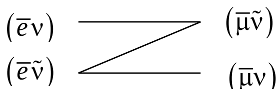
The new model allows the processes admitted by the additive character of lepton number conservation law.

2) The concepts of the four-component theory are expanded by addition of the tauon and the new fourth (l_4^+, ν_4) lepton families. Each (anti)particle is characterized by lepton number l in conformity with the table.

Leptons				l	Antileptons				l
e^-	ν_e^L	τ^-	ν_τ^L	+1	e^+	$\tilde{\nu}_e^R$	τ^+	$\tilde{\nu}_\tau^R$	–1
μ^+	ν_μ^R	l_4^+	ν_4^R	+2	μ^-	$\tilde{\nu}_\mu^L$	l_4^-	$\tilde{\nu}_4^L$	–2

It is supposed the conserving of the total lepton number L.

The currents on the upper and down straight lines of diagram



lead to the $(\nu_e \leftrightarrow \tilde{\nu}_\mu)$ and $(\nu_\mu \leftrightarrow \tilde{\nu}_e)$ conversions respectively. The mutual transitions between related neutral (anti)leptons $(\nu_e \leftrightarrow \tilde{\nu}_e)$ and $(\nu_\mu \leftrightarrow \tilde{\nu}_\mu)$ are forbidden. The currents disposing on the slanting line predict the decay mode $\mu^- \to e^- \tilde{\nu}_\mu \tilde{\nu}_e$.

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ISOMERIC STATE OF ^{229}Th AND ITS POPULATION IN THE REACTION OF THE COULOMB EXCITATION

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On the basis of a detailed analysis of γ-transitions in ^{229}Th arising in the α-decay of ^{233}U, it was found the existence in the ^{229}Th daughter nucleus of a low-lying state at the excitation energy as low as a few electron-volts. By now, it is the lowest lying state among all known nuclear states. According to the most recent experimental data [1], the energy of the aforementioned level is about 7.6 eV. In the paper [2], authors detected conversion electrons accompanying the γ-decay of this level, the energy of electrons was not determined, while the half-life of isomeric level was measured in [3] with the result $T_{1/2}$ = 7(1) μs. Our calculations performed in the framework of the unified nuclear model lead to $T_{1/2}$ = 5.9 μs, accounting for the electron conversion. The transition is predominantly of the $M1$ type. As the conversion coefficient $\beta(M1, \Delta E = 7.6\text{ eV}) = 1.4\cdot10^9$ and $\beta(M1) \sim \Delta E^{-3}$, and, the half-life of the isomeric state at such small values of ΔE in practice does not depend on the transition energy. Basing on our results we calculated cross section for excitation of isomer in the process of the Coulomb excitation. As the isomeric state is populated not only by the direct Coulomb excitation with cross section σ, but also due to decays to this level from the overlying nuclear states that are also excited in the CE, we also allowed for this process (effective cross section σ_{eff}). In our calculations, we considered direct excitation of all positive parity states of the [633] and [631] bands with $I \leq 9/2$, as well as all γ- and conversion transitions between them.

Level	Energy keV	Protons, 6 MeV		Protons, 10 MeV		^{4}He, 10 MeV	
		σ, barn	σ_{eff}, barn	σ, barn	σ_{eff}, barn	σ, barn	σ_{eff}, barn
$3/2^+$	0.0076	1.389(–4)	1.008(–3)	2.314(–4)	1.689(–3)	9.020(–4)	6.448(–3)

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NEUTRON EXCESS ODD-ODD ISOTOPES OF In CLOSE TO ^{132}Sn

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By now, there appeared essential information about the properties of odd-odd neutron-excess nuclei close to ^{132}Sn. Here, we calculated spectra and decay properties of these nuclei, from ^{130}In up to ^{138}In. By calculations of ^{130}In and ^{132}In, that are just close to the doubly-magical nucleus ^{132}Sn, we applied the RPA and shell model approaches, while for more heavy isotopes we used the multiparticle shell model. In Fig. 1 one can see spectra of negative parity levels that belong to the lowest configurations. In ^{130}In among the positive parity levels one can see the 1^+ (2.13 MeV) state having the leading configuration $\{\pi 1g9/2^{-1}, \nu 1g7/2^{-1}\}$ with the value $B(GT,\beta^-;0_1^+ \rightarrow 1_1^+) \approx 2.87$, as well as the low-lying 3_1^+ (0.24 MeV) state, which is the lowest level of the configuration $\{\pi 1g9/2^{-1}, \nu 2d3/2^{-1}\}$. In ^{132}In one can see the low-lying 5^- (0.04 MeV) state, which is an isomerical level with $T_{1/2}$ = 1 ms. For ^{134}In we also considered β^--decay from the ground state (7_1^-) to the excited 6_1^+ (1.25 MeV) of the ^{134}Sn. One can also mention the similarity of the energy splitting in ^{130}In and ^{138}In.

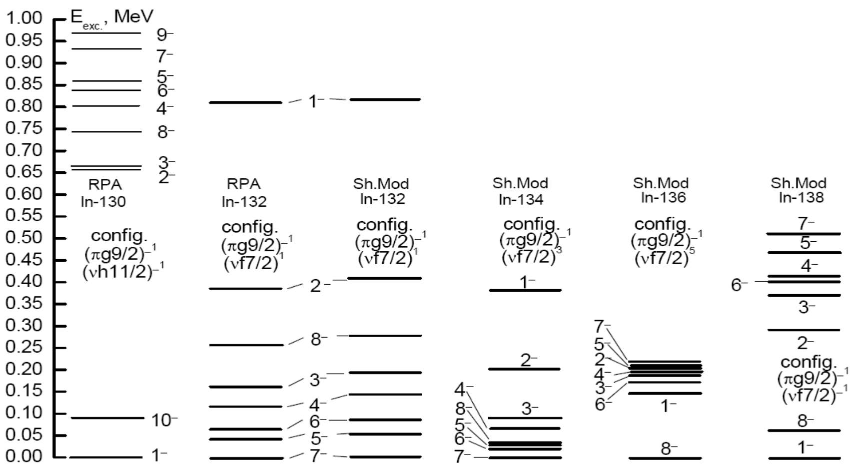

Fig. 1. Lowest negative parity states in the sequence of odd-odd neutron excess In isotopes.

POLARIZATION BREMSSTRAHLUNG IN ALPHA DECAY

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We consider a polarization bremsstrahlung (PBS) mechanism of formation of electromagnetic radiation [1, 2]. Internal PBS arises in α-decay as a result of the emission of photons by α particles due to their scattering from the internal atomic electron shells. This phenomenon was considered for the first time in [3] (see also [4]). The diagrams describing this mechanism are given in Fig. 1, where parts (a) and (b) correspond to the conventional bremsstrahlung (BS) and PBS, respectively.

This mechanism is examined for a ^{210}Po atom in comparison with the results of [5]. We calculate the relative contributions of PBS to the total BS cross section of photon emission in the α-decay of ^{210}Po nuclei with an account for the contributions of the *s* electrons of different shells of ^{210}Po atom. The calculations show that the contribution of PBS amounts to tens of percent for photon energies smaller than the binding energy of the *K* electrons in a ^{210}Po atom, which is equal to 96 keV.

It is shown that, when the photon energy does not exceed than the energy of the atomic *K* electrons, the polarization bremsstrahlung contributes significantly into the bremsstrahlung in α-decay.

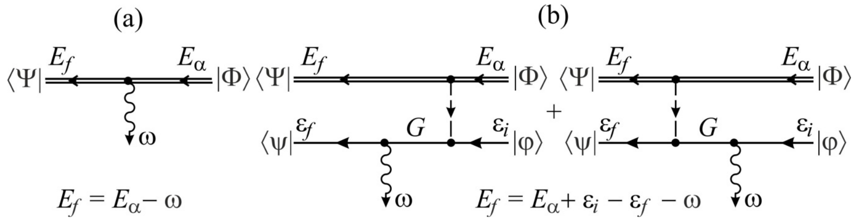

Fig. 1. Diagrams of the emission of a photon with the energy ω in α decay in (a) the first and (b) second orders of perturbation theory. Here, Φ(Ψ) is the initial- (final-) state wave function of the "α particle + daughter nucleus" system with energy E_α (E_f), φ (ψ) is the initial- (final-) state wave function of an electron with energy ε_i(ε_f), and G is the electron Green function.

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STUDY OF GROUND STATES OF ^{6,7,9,11}Li NUCLEI BY FEYNMAN'S CONTINUAL INTEGRALS METHOD

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The wave functions of the ground states of few-body nuclei ^{6,7,9,11}Li are calculated by Feynman's continual integrals method in Euclidean time [1–3]. The algorithm of parallel calculations was implemented in C++ programming language using NVIDIA CUDA technology [4]. Calculations were performed on the NVIDIA Tesla K40 accelerator installed within the heterogeneous cluster of the Laboratory of Information Technologies, Joint Institute for Nuclear Research, Dubna.

The studied isotopes are considered as cluster nuclei with the following configurations: ^{6}Li (α+n+p), ^{7}Li (α+n+n+p) ^{9}Li (^{7}Li+n+n), and ^{11}Li (^{9}Li+n+n). The probability density distribution for ^{6}Li (α+n+p) nucleus in the Jacobi coordinates with the vectors $\vec{x}$, $\vec{y}$, and the angle θ between them is shown in Fig. 1.

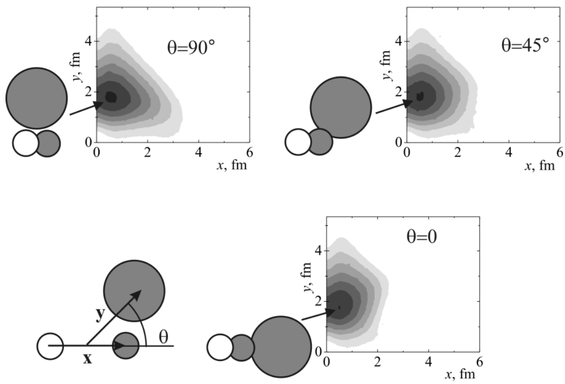

Fig. 1. The probability density for the ^{6}Li nucleus and the vectors in the Jacobi coordinates; neutrons and α-clusters are denoted as small empty circles and large filled circles, respectively, protons are denoted as small filled circles. The only one possible configuration is α-cluster + deuteron-cluster.

This work was supported by the Russian Science Foundation (RSF), research project 17-12-01170.

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ZERO-SOUND IN NUCLEAR MATTER WITH ASYMMETRY PARAMETER $-1 \leq \beta \leq 1$

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Zero-sound excitations in the isospin asymmetric nuclear matter are presented at $-1 \leq \beta \leq 1$ [1]. It is shown that in the asymmetric matter ($|\beta| \neq 0,1$) there are three complex branches of the solutions $\omega_{s\tau}(k,\beta)$, τ = p, n, np [1], in the symmetric matter ($\beta = 0$) there are two branches $\omega_s(k)$, $\omega_{s1}(k)$, and in the neutron matter (β = 1) there is one branch $\omega_{sn}(k)$. We use a special normalization of the quasiparticle effective interaction which is determined by the isospin depended density of states. As a result the branches $\omega_{sp}(k)$, $\omega_{snp}(k)$ disappear in the neutron matter and only $\omega_{sn}(k)$ survives (Fig. 1). In Fig. 1 it is shown how the real parts of two branches $\omega_{sn}(k,\beta)$ ('n') and $\omega_{sp}(k,\beta)$ ('p') are changed and turn one into another with β increasing for three values of k. We have two specific values of k: $k_t(\beta)$ and k_c [1].When $k \leq k_t(\beta)$ the branch $\omega_{sn}(k,\beta)$ is real at $\beta>0$ and $\omega_{sp}(k,\beta)$ at $\beta<0$. In Fig. 1 the path from $\omega_{sp}(k,\beta)$ to $\omega_{sn}(k,\beta)$ with β increasing is shown by the solid curve. At $\beta = 0$ the branches turn into $\omega_s(k)$ ('s'). But there is not transition from the complex $\omega_{sn}(k,\beta)$ to $\omega_{sp}(k,\beta)$ with β increasing. When $k \geq k_c$ a continuous path from $\omega_{sp}(k,\beta)$ to $\omega_{sn}(k,\beta)$ (and back) is shown by the dashed curves. At $\beta = 0$ the branches cross the point $\omega_{s1}(k)$ ('$s1$'). At $k_t(\beta) \leq k \leq k_c$ the solutions are presented by the dotted curves and the arrows near $\beta = 0$ point out that we can not go from $\omega_{sp}(k,\beta)$ to $\omega_{sn}(k,\beta)$ (from $\omega_{sn}(k,\beta)$ to $\omega_{sp}(k,\beta)$) continuously changing β only. We are to choose a path over k and β which travel around the "critical" point $k = k_c$.

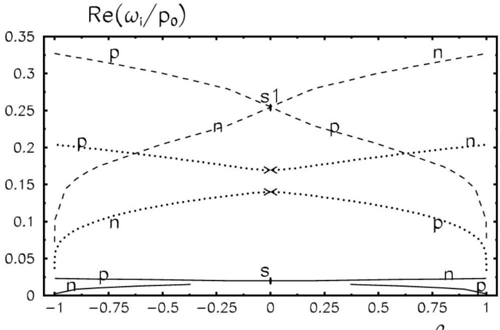

Fig.1. Dependence of $\omega_{sp}(k,\beta)$ and *$\omega_{sn}(k,\beta)$ on β for three values of k. p_0 = 0.268 GeV.*

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MANY BODY INTERACTIONS IN NUCLEAR MATTER

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We continue our studies of nuclear matter in framework of the QCD sum rules approach [1]. The nucleon parameters m^* and Σ_V are expressed in terms of QCD condensates. The vector condensate $\nu(\rho)=\langle M|\sum_i \bar{q}^i\gamma_0 q^i|M\rangle$ and the scalar condensate $\kappa(\rho)=\langle M|\sum_i \bar{q}^i q^i|M\rangle$ are the most important ones. While $\nu(\rho)$ is just proportional to the baryon density ρ the calculation of $\kappa(\rho)$ requires some assumptions on structure of the vector of state of nuclear matter $|M\rangle$.

One can start with viewing $|M\rangle$ as a system of noninteracting nucleons. This would correspond to inclusion of 2*N* forces in the nucleon parameters m^* and Σ_V. Inclusion of 2*N* forces in the state $|M\rangle$ provides the 3*N* forces for m^* and Σ_V, etc. It is known [2] that the contributions to κ are dominated by the pion exchanges. Note that the single pion exchange is treated here as a 2*N* interaction.

Now we develop another approach, dealing with the pion-dressed nucleons. The one-pion exchange can be considered as the nucleon self energy in the matter. Thus it can be included into the single particle wave function. The same refers to iterated one pion exchange. This forms the gas of quasifree nucleons as a starting point. In the first step κ is the sum of condensates created by each of the quasifree nucleons of the matter separately, providing m^* and Σ_V in the 2*N* approximation. The two-body interactions (pion exchanges) between the quasifree nucleons of the matter provide the contributions of 3*N* forces to m^* and Σ_V, etc. In this approach we obtain the strict hierarchy of contributions of the many body forces to the effective mass m^*, to the vector self energy Σ_V and to the potential energy *U*. We find m^*=433 MeV for the gas of quasifree nucleons at the phenomenological value of saturation density. The 3*N* forces increase the value by 174 MeV, 4*N* forces add 24 MeV more. The vector self energy is 207 MeV for the quasifree nucleons. The 3*N* and 4*N* forces increase the value by 24 and 9 MeV correspondingly. Here the main contribution to 3*N* and 4*N* forces comes from the four quark condensates. The potential energy for the quasifree nucleons is 288 MeV. The 3*N* and 4*N* interactions add 150 and 33 MeV correspondingly. The main contributions of the 3*N* and 4*N* forces come from the change of m^* and are caused by the two-pion exchanges with the delta isobars in the intermediate state.

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ON THE DOUBLE SPIN ASYMMETRIES IN THE ELASTIC SCATTERING OF ELECTRONS OFF PROTONS

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Recent polarization experiments [1, 2] on electron-nucleon scattering have profoundly extended our understanding of the nucleon electromagnetic form factors (observation of the rapid decrease of the ratio G_E^p / G_M^p for momentum transfers $Q^2 \geq 1$ GeV^2).

According to contemporary experiment setup one can distinguish between studies of Single Spin Asymmetry (SSA) and Double Spin Asymmetry (DSA).

As an example of the former case we can recall experiments using longitudinally polarized electron beams scattered on the proton target to search and investigate parity violation due to interference of the weak and electromagnetic interactions. SSA in this case is well known right-left asymmetry A_{RL}.

Case of DSA, considered in [3, 4] may be called as Asymmetry of Asymmetry: right-left asymmetry of the transverse to reaction plane asymmetry $A_p^{(\perp)}$ in [3], and right-left asymmetry of the mirror asymmetry $A_p^{(M)}$ in [4].

Here we consider two types of DSA in the elastic scattering of longitudinally polarized (with helicity $h = \pm 1$) electrons: 1) on polarized $(\vec{s})$ proton target with unpolarized recoil proton, leading to double spin correlations $h(\vec{n}\,\vec{s})$, and 2) on unpolarized proton target with polarized $(\vec{s}')$ recoil proton, leading to double spin correlations $h(\vec{n}\,\vec{s}')$, where $\vec{n}$ is a unit vector in the direction of the electron beam. In both cases essential role plays double spin correlation of time-reversal violating type $h(\vec{s}[\vec{n}\vec{m}])$ or $h(\vec{s}'[\vec{n}\vec{m}])$, with $\vec{m}$ being a unit vector in the direction of the scattered electron.

The DSAs considered can help to clarify possibilities to detect violation of the *P*- and *T*-invariances due to electroweak interference with account of anapole and electric dipole form factors of the proton.

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THE POSSIBILITY OF EXISTENCE OF THE NEUTRON STABILITY PENINSULA OF NUCLEI FOR NEUTRON MAGIC NUMBER *N* = 126

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The ground state properties calculations of even-even nuclei with extreme neutron excess have been carried out beyond the theoretically known neutron drip line on the base relativistic Hartree-Bogoliubov (RHB). The RHB method with DD-PC1 and DD-ME2 forces has been used with the accounts of axial deformations (we have employed the known numerical code DIRHB [1]). These calculations are continuation of our investigations of nuclei with extreme neutron excess by the Hartree-Fock method with Skyrme forces [2]. It is shown that the isotone chain with the neutron number $N = 126$ as well as in [2] forms the peninsula of nuclei beyond the neutron drip line which are stable against one and sometimes two neutrons emission. The neutron and proton density distributions of nuclei belonging to this peninsula possess spherical symmetry. The mechanism of stability restoration beyond the neutron drip line results from the full filling of neutron subshells with large angular momentum. The quasistable states of this type are bounded by a large centrifugal barrier and at partial filling these states belong to the continuous spectrum. When the number of neutrons increases, the states with large j get filled and intrude into the discrete spectrum. It has been shown that the formation of the peninsula of stability in the (N, Z) space beyond the neutron drip line while adding neutrons to extremely neutron-rich isotopes is stable to the choice of type forces (DD-PC1 or DD-ME2) and take place at the same value of $N = 126$ irrelatively the type forces. The results for long isotope chain of Pd up to the neutron drip line are compared with the RHB [3].

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THE INVESTIGATION OF Zr ISOTOPES PROPERTIES IN APPROXIMATION OF RELATIVISTIC AND NONRELATIVISTIC SELF-CONSISTENT MEAN FIELD

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We studied the ground state properties of Zr isotopes from the proton drip-lines up to the neutron drip-lines based on the methods Hartree-Fock with Skyrme forces (HF+BCS) [1] and relativistic Hartree-Bogoliubov (RHB) accounting deformation. We used parameters of Skyrme forces Ska, Sly4 and SkM* in HF+BCS calculations. The RHB method with DD-PC1 and DD-ME2 forces was used with the accounts of axial deformations (we have employed the known numerical code DIRHB [2]). The main purpose of this study is the investigation of possible manifestations of nuclear deformation of neutron-rich Zr isotopes for description of sharp increase of mean square radius of charge distribution known from the experiment at the transition from ^{98}Zr to ^{100}Zr. Both types of HF+BCS and RHB calculations showed dependence of the received results from the values of parameters of the used pairing forces. The separable pairing interaction with different constants was used in RHB approximation as well as in works [2, 3]. We studied the influence of pairing interaction forces on different characteristics of Zr isotopes at A = 88–102. We also calculated the dependence of binding energies values of the investigated isotopes from quadrupole deformation parameters β for different constants of pairing interaction. The influence of nuclear deformation and pairing forces on changes of mean square radius of Zr isotopes were studied. For the neutron-rich Zr isotopes c $A \geq 98$, states with very large deformation parameters $\beta \sim 0.5$ of nuclei can be realized. Comparison of the calculated results of the main characteristics of Zr isotopes in HF+BCS and RHB was made.

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QUANTUM-MECHANICAL SIMULATION OF MULTIELECTRON ATOMS IN STRONG EXTERNAL FIELDS

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The paper is devoted to the *ab initio* numerical simulation of the evolution of multielectron atoms (such as argon, krypton, and other noble gas atoms) during the interaction with an intense external laser field. In the process of this interaction ionization of atoms occurs, and newly born free electrons are accelerated and create large electronic currents that emit secondary electromagnetic radiation. The study of these processes is currently of great importance for the development of efficient methods for generation of radiation in hard-to-reach frequency ranges [1–3] (in particular, in terahertz, mid-infrared, UV, XUV, and soft *X*-ray ranges), and also for the development of spectroscopic methods using the secondary radiation [4].

The numerical simulation carried out in this work is based on the solution of the time-dependent Kohn-Sham equations in which the Hamiltonian for individual orbitals includes the interaction with the atomic nucleus, electron-electron Coulomb, and exchange-correlation interaction, as well as interaction with the electric field of the laser pulse [5, 6]. Particularly, we show that for a sufficiently large number of electrons in the outer shell of an atom, the action of an external electric field leads to a significant polarization of the outer shell. This polarization creates a screening of the external field and leads to a decrease in the probability of tunneling ionization of atoms and an increase in the number of neutral atoms participating in the generation of secondary radiation. At large peak intensities of laser pulses, this corresponds to a significant increase in the efficiency of generation of high harmonics of laser radiation in comparison with the case when the dynamics of the outer shell of an atom are not taken into account.

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ISOVECTOR QUANTAL FLUCTUATIONS IN THE SUPERHEAVY DI-NUCLEAR SYSTEMS AND THE FISSION FRAGMENT CHARGE DISTRIBUTIONS

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The fission fragment isobaric chain charge distributions are important probe for nuclear fission dynamics. Isovector quantal excitations during the large scale collective motion from saddle to scission point influence on the charge polarization and charge splitting between fission fragments. The isobaric charge width is considered as a result of a frozen quantal fluctuation at scission point [1]. The isovector nuclear density degree-of-freedom oscillations are much faster than the deformation and mass ones. The collective isovector potential is calculated for the di-nuclear system of deformed fragment at the minimum of the potential energy at scission point. The fission fragment deformation energies were calculated using the macroscopic-microscopic approach. The average charge asymmetry and the stiffness parameter of the collective potential are obtained by the parabolic approximation of the calculated potential energy at the fixed mass asymmetry. The charge width of the fission fragment isobaric chain is determined mainly by the of collective ground-state wave function. Results of calculations of the fragment isobaric chains charge distribution parameters in the spontaneous fission superheavy nuclei with $104 \leq Z \leq 118$ will be presented.

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INVESTIGATION OF THE THRESHOLD BEHAVIOR OF ^{234}U(n, *f*) REACTION

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The cross section of ^{234}U(n,*f*) reaction in the energy range 0.7–0.9 MeV has a resonance like behavior, with the "resonance" width of about 200 keV (Fig.1, fissibility according to ENDF/B-VII.1 neutron library). In the same energy range the sharp variation of the fission fragment anisotropy was also observed [1].

Two different mechanisms for this behavior were proposed. In the first one the "resonance" is due to competition between the fission and inelastic channels near threshold. In the second one this behavior of the cross section is due to the presence of the resonance vibrational excitation of class III in the second isomeric potential well. These two different explanations of the fission cross section are discussed. Calculated cross section of fission (fissility) and the anisotropy of the fragments are compared with the experiment.

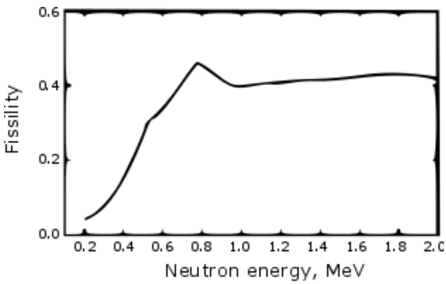

Fig. 1. Fissility of ^{234}U for different neutron energies.

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DESCRIPTION OF CONTINUUM STATES WITHIN NO-CORE SHELL MODEL. SINGLE-STATE HORSE METHOD

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We present a new Single-State HORSE method [1, 2] allowing us to calculate low-energy scattering phase shifts and resonance energy and width within the nuclear shell model. The Single-State HORSE technique is based on the general properties of the oscillator basis and on the harmonic oscillator representation of scattering equations (HORSE); it utilizes general low-energy expansions of the *S*-matrix including the poles associated with bound and resonant states or analytic properties of partial-wave scattering amplitudes [3].

We extended the Single-State HORSE method to the case of reactions involving charged particles [4]. The approach used here relies on the HORSE method generalization to the case of Coulomb scattering [5] and on the parametrization of the phase shifts in the low-energy region based on the analytic properties of Coulomb-modified partial-wave scattering amplitudes.

Note that this new method makes it possible to describe correctly the behavior of the phase shifts not only in the resonance region but also at energies tending to zero.

The Single-State HORSE method is carefully verified using a model two-body problem with a Woods-Saxon type potential and is shown to be able to obtain accurate scattering phase shifts and resonance energy and width even with small oscillator bases.

The Single-State HORSE method is successfully applied to the study of the nα- and pα-scattering phase shifts and resonances based on the no-core shell model calculations of ^{5}He, ^{5}Li and ^{4}He nuclei with the realistic JISP16 and Daejeon16 *NN* interactions. Both JISP16 and Daejeon16 provide a good description of the $3/2^-$ and $1/2^-$ resonances in ^{5}He and ^{5}Li nuclei as well as of the $1/2^+$ non-resonant nα- and pα-phase shifts.

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CONTRIBUTION OF TRANSFER DIRECT MECHANISMS TO $^{15}N(\alpha,p)^{18}O$ REACTION PROTON SPECTRA

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Angular distribution of protons from $^{15}N(\alpha,p)^{18}O$ reaction at 30 MeV α-particle energy is calculated within direct mechanisms of light and heavy cluster transfer (Fig. 1), realized in code FRESCO [1], and within by compound nucleus model at Hauser-Feschbach approach [2].

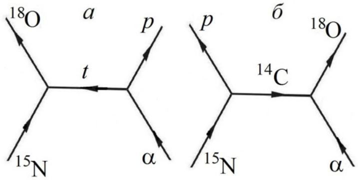

Fig. 1. Mechanisms of cluster direct transfer at $^{15}N(\alpha, p)^{18}O$ reaction.

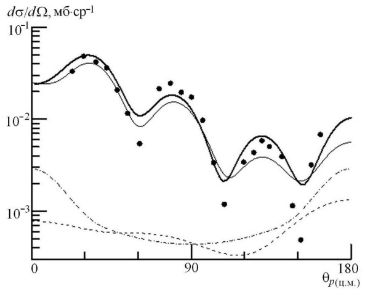

Fig. 2. Angular dependence of differential cross sections of $^{15}N(\alpha, p)^{18}O$ reaction various mechanisms: thin solid line – pickup of a triton, dotted – transfer of heavy ^{14}C cluster, dot-dash – mechanism of compound nucleus, fat solid – summarized cross section.

Calculated cross sections are compared with experimental [3]. Model parameters are picked up for the best compliance of calculations with experiment. Angular dependences of all three mechanisms cross sections are presented in Fig. 2.

Results have shown that the main contribution to proton formation is provided by transfer of triton cluster. The role of the heavy ^{14}C cluster transfer mechanism is noticeable at angles larger than 90°. The cross section of compound nucleus mechanism considering all energetically resolved channels is symmetric relatively 90° and gives a noticeable contribution only at large angles. The summarized cross section well corresponds to experimental dependence. Some divergence is connected with a possibility of additional mechanisms which can give a contribution to the cross section of this reaction.

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POLARIZING CHARACTERISTICS OF $^{24}Mg(2^+)$ NUCLEUS FORMED IN $^{27}Al(p,\alpha)^{24}Mg(2^+)$ REACTION

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The polarization tensors $T_{k\kappa}(\theta_y)$ of aligned nuclei with spin J are the essential physical characteristics that one can be restored from correlation experiments (reaction A(x, $y\gamma$)B). We have restored the $T_{k\kappa}(\theta_\alpha)$ for $^{24}Mg(2^+)$ nucleus on the basis of spin-tensors $\rho_{k\kappa}(\theta_\alpha)$ partially obtained earlier [1] in a coordinate system with the axis Z, directed along the proton beam. $T_{k\kappa}(\theta_y)$ are defined in coordinate frame where quantization axis Z is orthogonal to reaction plane

$$T_{k\kappa}(\theta_y) = \sum_{\pm\kappa',\mathrm{even}} \frac{\rho_{k\kappa'}(\theta_y)}{\rho_{00}(\theta_y)} \cdot D^{\kappa}_{\kappa'\kappa}(\pi/2, \pi/2, \pi).$$

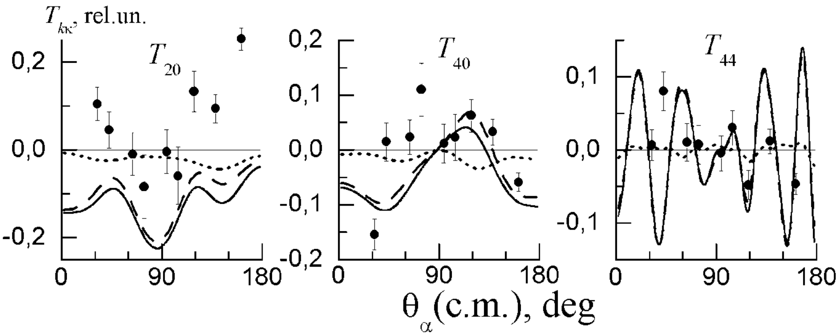

Fig. 1. Tensor polarization components $T_{k\kappa}(\theta_\alpha)$ of the $^{24}Mg(2_1^+)$ nucleus formed in the reaction $^{27}Al(p,\alpha)^{24}Mg(2^+)$ at E_p = 7.4 MeV. Points – the restored experimental values, solid curves – calculation for the sum of the mechanisms triton pickup (dashed) [2] and the compound nucleus formation (dotted)[3].

Some of the tensor components are shown in Fig. 1. The results show that the components with zero projections (κ = 0) are comparable in magnitude with non-zero ones. Tensor polarization depends strongly on the final particle exit angle. It was found also that the obtained angular dependences of $T_{k\kappa}(\theta_\alpha)$ are similar to the corresponding dependences from the inelastic scattering of protons and deuterons on ^{24}Mg at $E_x \approx 7.5$ MeV per nucleon [4].

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PROTON TRANSFER IN REACTIONS ^{3}He + ^{197}Au, ^{194}Pt

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The experimental data on the formation cross sections for isotopes ^{197}Hg in reaction ^{3}He + ^{197}Au and ^{194}Au in reaction ^{3}He + ^{194}Pt [1] are analyzed based on the solution of the time-dependent Schrödinger equation [2] in combination with calculations within the statistical model using the computational code of the NRV knowledge base [3].

The comparison of the experimental data on the formation cross section for the ^{194}Au isotope in the ^{3}He + ^{194}Pt reaction with the results of calculations is shown in Fig. 1. It can be seen that this isotope is mainly formed via the transfer process. Two mechanisms of transfer are proposed. The first mechanism consists in the transfer of proton to the high excited states of the target followed by its drop to the lower levels and the subsequent neutron evaporation due to the energy gain. The second mechanism is the transfer of proton from the projectile to the target combined with the transfer of the neutron from the target to the projectile leading to the formation of the ^{3}H nucleus.

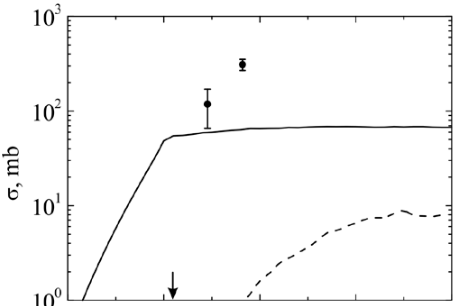

Fig. 1. Cross section for the formation of the ^{194}Au isotope in the ^{3}He + ^{194}Pt reaction: dots are experimental data from [1], the solid curve is an estimation of the contribution of evaporation of a neutron after proton transfer. The dashed curve is the contribution of the fusion-evaporation process calculated using the statistical model code of the NRV web knowledge base [3]. The arrow indicates the position of the Coulomb barrier.

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COMPARISON OF APPROACHES BASED ON DIFFERENT ALGEBRAIC VERSIONS OF THE RESONATING GROUP MODEL FOR RADIATIVE CAPTURE

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At the present time, theoretical approaches for radiative capture are required to obtain the cross sections (astrophysical *S*-factors) of the corresponding reactions in the low-energy range, which is inaccessible for reliable experimental measurements because of the sizeable Coulomb barrier. Among these approaches, the microscopic ones [1–6] are of the largest interest to the modern nuclear theory.

In our previous works [4–6], the microscopic approaches to radiative capture reactions were developed using different algebraic versions of the resonating group model (AVRGM) [7]. The main aim of the present work is to compare the single-scale and multiscale AVRGM. Their specific features are reviewed. The descriptive capabilities are demonstrated by calculating partial and the total astrophysical *S*-factors for particular reactions and comparing with experimental data. The further prospects are discussed.

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A NON-EQUILIBRIUM EQUATION OF STATE AND EMISSION OF HIGH ENERGY PARTICLES IN HEAVY ION COLLISIONS

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To describe the collisions of heavy ions and to find the equation of state of a nuclear matter, it is natural to choose the hydrodynamic approach (see, for example, [1]). The dynamics of heavy ion collisions involves the use of a non-equilibrium equation of state [2–4] taking into account the effects of nuclear viscosity. This allowed describing energy spectra of protons, pions, and fragments for the collisions of different nuclei at the medium-energy range [3 – 5]. However, "high-energy tails" of proton spectra obtained in [6], as it turned out, are not reproduced near the kinematic limit of the spectrum. They turn out more harden when we use a large canonical ensemble for the distribution function of emitted protons. In this paper, we succeeded to introduce an amendment with account of the microcanonical distribution in the high-energy part of the spectrum to reproduce experimental data [6] without breaking the agreement with other data. In addition, we succeeded to reproduce the high-momentum proton distributions in the reaction $^{12}C + {}^{9}Be \rightarrow p + X$ at the ^{12}C ion energy of 300, 600, 950 and 2000 MeV/nucleon at the angle of 3.5° [7], which are related to the cumulative region and are not quite well described by "molecular dynamics" and other cascade models.

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SCATTERING OF PROTONS ON CARBON ISOTOPES $^{9,13,15}C$ IN THE GLAUBER APPROXIMATION

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Recently, the study of the carbon isotope has been carried out in several directions: measurement and analysis of the cross sections for interaction and reactions on light targets (starting with hydrogen), elastic scattering in the field of a heavy nucleus, and the nucleon transfer reaction.

In this paper we calculate the differential cross sections (DSs) of elastic protons scattering on $^{9,13,15}C$ nuclei at the intermediate energies from hundreds of MeV/nucleon to 1.0 GeV/nucleon. The Glauber's diffraction theory, in the framework of which the calculation is performed, makes it possible to study the scattering process "microscopically", i.e. to estimate the contribution to the cross section from different scattering multiplicities and to determine the effect of the nucleus structure on it. The wave functions of the $^{13,15}C$ nuclei, used by us, are calculated in the many-particle shell model [1, 2]. The wave function of the ^{9}C nucleus is in the three-body ^{7}Be+p+p model [3].

The calculated DSs of protons scattering on the studied nuclei have been compared with the results obtained in other formalisms.

Based on the results of DSs calculation, the following conclusions can be made.

More clear diffraction pattern is observed with the growth of the collision energy in DSs: the number of maxima and minima in the same angular range increases.

The cross section for single scattering dominates at small angles, the cross section for double scattering dominates at larger scattering angles. In the regions where one- and two-fold partial cross sections have the comparable magnitude, minima arise in the total cross section due to the destructive interference of these terms.

In the scattering cross section, calculated in the optical limit, the maximum contribution is made by collisions with the 1*p*-shell nucleons, the minimum contribution – with the 2*s* -shell nucleon.

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THE INFLUENCE OF COLOR RECONNECTION AND JET FORMATION EFFECTS ON CHARGE PARTICLE TRANSVERSE MOMENTUM DISTRIBUTION IN p+p COLLISIONS AT LHC ENERGIES

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The influence of the color reconnection processes and the hadronic jet formation on the inclusive charge particle transverse momentum distribution in p+p collisions is analyzed with the PYTHIA 8 event generator [1]. The dependencies of the mean transverse momentum of charge particles on rapidity and pseudorapidity are found and the influence of these processes on them is studied.

It is demonstrated that the results depend significantly on the fact for which interval – rapidity or pseudorapidity, – the transverse momentum distributions are obtained, what is important when comparing these distributions with experimental data. In particular, it is shown that the account of the kinematical factor, arising at description of the transverse momentum distribution in a given pseudorapidity interval, considerably improves the description of the experimental data obtained by the CMS collaboration in 7 TeV, p+p collisions at LHC, in the region of a small transverse momentum [2].

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GENERALIZED MULTIPOMERON EXCHANGE MODEL

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A generalization of the multi-pomeron exchange model [1–5] is proposed to describe the nucleus-nucleus collisions at high energy taking into account the yield of hadrons containing heavy quarks. The main feature of this model is the effective consideration of string collectivity with the help of the dedicated parameter relevant to the modification of string tension in case of string fusion process. In this model, an increase in the string tension, in a certain class of events with high multiplicity, allows the creation of particles containing *c* quark in the process of string fragmentation. The model parameters are fixed from the data on main multiplicity dependence of the transverse momentum at pp and $p\bar{p}$ collisions over a wide energy range (from ISR to LHC). The multiplicity of strange and charm particles, their transverse momentum, and correlations are obtained at the LHC energy. The predictions of the model are compared to the experimental data.

The research was supported by the grant of the Russian Science Foundation (project 16-12-10176).

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CLUSTERING IN MULTIDIMENSIONAL POTENTIAL ENERGY SURFACE CALCULATIONS

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In a series of experiments a new ternary fission channel of low excited heavy nuclei has been observed [1]. The obtained experimental results initiated a number of theoretical studies devoted to the clustering in fission [2–4].

To study the effects of clustering on the fission mode formation a comprehensive Strutinsky-type [5] calculations have been performed for a wide range of nuclei in actinide region. We consider a stabilization of internal cluster structure of the nuclear system under the fluctuations of the asymmetry value used as a constraint in the multidimensional shell correction calculations. Potential Energy Surfaces (PES) are calculated using realistic nuclear potential with constant thickness of the surface layer for strongly deformed nuclear shapes in high-dimensional deformation space.

Fission as a statistical decay is governed by the phase space evolution in the different decay channels, generally assumed to be related to the valleys in the PES-landscape. The population of a fission mode is determined by the PES minima configuration and its energy value. The complexity of the PES seems to arise from the possibility of the competition within the "pre-process" of clustering.

The multidimensionally constrained minima searching procedure is applied to analyze a continuous sequence of shapes from the sphere to two-, three-, and four-fragment scission configurations.

It is shown that persistent cluster magic shell structures play a main role in the origination of various fission modes. A number of different state space scales is introduced into the compound nuclear system by clustering. The calculated PES's show a complex topological structure including several pronounced local minima for the several ternary fragmentation channels.

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COMPARATIVE MDWBA ANALYSIS OF NUCLEON TRANSFER REACTIONS ON ^{24,25}Mg FOR ANC OBTAINING

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The actual task is obtaining the correct "experimental" values of the asymptotical normalization coefficients (ANC) for the bound single particle nucleon states in light nuclei which define a contribution of direct mechanisms in the astrophysical relevant reactions and extracted mainly from the nucleon transfer reactions. Here the analysis of available experimental differential cross sections (DCS) of the proton transferring ^{24}Mg(d,n)^{25}Al, ^{24}Mg(^{3}He,d)^{25}Al and neutron transferring ^{24}Mg(d,p)^{25}Mg, ^{25}Mg(d,t)^{24}Mg reaction have been fulfilled. Some experimental DCS for such processes as the elastic ^{24,25}Mg+d scattering and ^{25}Mg(d,t)^{24}Mg reaction at the energy E_{d} = 14.5 MeV were measured additionally at the beam of the isochronous cyclotron U-150M (INP ME of Kazakhstan). The first step of analysis was made in the framework of modified DWBA (MDWBA, see for example [1]), assuming one step mechanism of the nucleon transferring. It is proposed that possible ambiguities of the extracted information ("experimental" values of ANC and spectroscopic factors (SF)) will point out the cases where the made assumption is wrong, and more complicated mechanisms should be taken into account, such as *D*-component of the deuteron, its break up, channels coupling etc. Using the criteria, formulated in MDWBA and experimental data on ^{24}Mg(d,n)^{25}Al reaction (E_{n} = 7 and 9 MeV, [2]), ^{24}Mg(^{3}He,d)^{25}Al (E_{3He}= 20, 25, 33 and 38.5 MeV, [3–6]) we find that the proton transferring is practically pure peripheral for forward escape angles of ejectiles. The extracted ANC squared $C^{2}_{\mathrm{24Mg+p}}$ values vary in the region 4.5–5.7 fm^{-1} and do not demonstrate clear energy dependence. Examination of the neutron transferring ^{24}Mg(d,p)^{25}Mg (E_{d} = 13.6 [7], 14.5 MэВ) and ^{25}Mg(d,t)^{24}Mg (E_{d} = 14.5, 14.8 [8], 18, 25 MeV [9]) shows that contribution of the interior of nuclei to the (d,p) reaction is ~20% whereas at the (d,t) reaction it is negligible. The $C^{2}_{\mathrm{24Mg+n}}$ values fall with deuteron energy increase in the region 2.13–1.64 fm^{-1}, what can be conditioned by contribution of not one-step mechanisms.

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THE DESCRIPTION OF TWO-PROTON VIRTUAL DECAYS OF THE SPHERICAL NUCLEI IN THE FRAMEWORK OF THE SUPERFLUID MODEL OF NUCLEI

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In the framework of the theory of two-step virtual two-proton decays [1] the partial widths and angular distributions of emitted protons for two-proton decays of ground states of parents nuclei with even numbers of protons Z Ne-16, Mg-19, Fe-45, Ni-48, Kr-67 into ground states of corresponding daughter nuclei are investigated. The angular distribution $W(\theta)$ of emitted protons in the coordinate system whose axis z is chosen in the direction of the emission of one of the protons is represented by using the notation of [1] in the form:

$$W_0(\theta) = \sum_{nlj}\sum_{m=0,1}\int_0^{Q_0} dT_1 \left\{ \left[Y_{lm}(\theta)\sqrt{a(lj)G^Z(nlj)}\sqrt{a(lj)G^Z(nlj)}\sqrt{\Gamma^{A-1}(nlj)}\sqrt{\Gamma^A(nlj)} \right] \Big/ \left[Q_1(nlj) - T \right] \right\}^2 \quad (1)$$

$a(lj)$, $b(lj)$ are the coefficients depending on l, j, $G^Z(nlj)$ is the amplitude of the superfluid spectroscopic proton factor determined in the framework of the superfluid atomic nucleus model for even and odd Z nuclei [2] as $G^Z(nlj) = \sqrt{(2j+1)/2}(-1)^l v^Z(nlj)$ for even Z and $G^{Z-1}(nlj) = u^{Z-2}(nlj)$ for odd Z. The total width Γ of the investigated two-proton decays of the parent nucleus is determined by the integration over the solid angle $d\Omega$ of the angular distribution (1). The calculation of the widths of the one-proton decays Γ^A, Γ^{A-1}, entering into the formula (1), is fulfilled with the proton shell model nuclear potential of the form: $V_{pA-1} = q(V_N + V_{ls})$, where V_N and V_{ls} are the central and the spin-orbital potentials. The parameter q and the pair interaction constant g_Z determined in the framework of the superfluid model of a spherical nucleus [2] are adjustable parameters. By varying of these parameters the numerical values of total widths for the two-proton decays were adjusted to its experimental values. As can be seen from Table, where the calculated and experimental values of the widths Γ^A are presented, the named above widths for all the cases studied are in agreement.

Nucleus	Ne-16	Mg-19	Fe-45	Ni-48	Kr-67
Γ^{exp}, MeV	0.0011(1)	$1.1^{+1.4}_{-0.25}\cdot 10^{-10}$	$1.6(5)\cdot 10^{-19}$	$2.2(1.1)\cdot 10^{-19}$	$0.620(26)\cdot 10^{-19}$
Γ^{th}, MeV	0.0012	$2.4\cdot 10^{-10}$	$1.77\cdot 10^{-19}$	$1.56\cdot 10^{-19}$	$0.618\cdot 10^{-19}$

At the same time the theoretical proton angular distributions (1) reasonably coincide with corresponding experimental distributions.

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THE COLLATION OF CHARACTERISTICS OF *T*-ODD ASYMMETRIES IN CROSS SECTIONS OF TERNARY FISSION REACTIONS BY COLD POLARIZED NEUTRONS FOR THE CASES OF THE EMISSION OF PRESCISSION AND EVAPORATION THIRD PARTICLES

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In the framework of the quantum theory of fission [1], formulae were constructed for the coefficients $D(\Omega)$ of *T*-odd asymmetries in the differential cross sections of the ternary fission of actinide nuclei by cold polarized neutrons with emission of prescission α-particles:

$$D(\Omega) = D_{\text{odd}}(\Omega) + D_{\text{ev}}(\Omega) = \frac{d\left\{P^0_{\text{odd}}(\theta)\right\}}{d\theta}\frac{\cos\varphi}{\left\{P^0(\theta)\right\}}\Delta\theta_{\text{odd}} + \frac{d\left\{P^0_{\text{ev}}(\theta)\right\}}{d\theta}\frac{\cos\varphi}{\left\{P^0(\theta)\right\}}\Delta\theta_{\text{ev}}, \quad (1)$$

where $\Delta\theta_{\text{odd(ev)}}$ are the effective angles of rotation of the direction of emission-particles with respect to the direction of emission of the light fission fragment, which take into account the influence of the Coriolis interaction on the angular distributions of fission fragments and α-particles. The experimental values $D_{\text{ev}}(\Omega)$ of the coefficients found in [2] correspond to positive signs $\Delta\theta_{\text{ev}}$ in (1) for the target nuclei ^{235}U, ^{239}Pu, ^{241}Pu and negative sign for ^{233}U. At the same time, the signs $\Delta\theta_{\text{ev}}$ obtained in [3] with the use of trajectory calculation methods are positive for all target nuclei ^{233}U, ^{235}U, ^{239}Pu, ^{241}Pu.

Formula (1) makes it possible to describe *T*-odd asymmetries in the reactions of ternary fission of nuclei with emission of evaporative γ-quanta and neutrons with the exception of the first term (due to the even character of the unperturbed angular distributions of the evaporation particles) and excluding the evaporation direction from $\Delta\theta_{\text{ev}}$ the angles of rotation particles (because of the large values of the Coriolis forces in the region of the appearance of thermalized fission fragments). In an experimental paper [4], it was shown that the signs of the rotation angles $\Delta\theta_{\text{ev}}$ for evaporative γ-quanta and neutrons coincide, but these signs differ for target nuclei ^{233}U and ^{235}U. This difference may be due to the difference of signs $\Delta\theta_{\text{ev}}$ shown above for prescission particles in the case of target nuclei ^{233}U and ^{235}U.

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ON DIRECT ONE-NEUTRON DECAY OF THE GIANT DIPOLE RESONANCE

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Experimental and theoretical studies of direct one-nucleon decays of any giant resonance carry information about the microscopic structure and decay mechanisms of high-energy particle-hole-type nuclear excitations. In the present work, we implement the newly developed particle-hole dispersive optical model (PHDOM) [1] to a description of direct one-neutron decay of the giant dipole resonance (GDR) in closed-neutron-shell nuclei. The first attempt of such a description has been undertaken in Ref. [2] for ^{208}Pb. Being somewhat improved recently [3], the method of Ref. [1] is used in this work to describe partial and total branching ratios for direct one-neutron decay of the GDR in ^{48}Ca, ^{90}Zr, ^{132}Sn and ^{208}Pb nuclei. The method includes evaluation within the PHDOM of the photo-absorption cross section and the cross section of the partial direct + semi-direct (γ,n)-reaction accompanied by population of a certain one-hole state in the product nucleus. Then the partial branching ratio is defined as the ratio of the mentioned (γ,n)-reaction cross section integrated over a GDR region to the photo-absorption cross section integrated over the same energy region. If this region is limited by the threshold of two-neutron emission, the total direct-decay branching ratio is, actually, the ratio of the direct to total (i.e., direct+statistical) one-neutron decay probabilities for the considered GDR. No specific adjustable parameters are used in the above-described evaluation of the branching ratios within the PHDOM. All the model parameters are taken from independent data, including the experimental energy and total width of the GDR in the considered nuclei. The quantitative estimation of the total direct one-neutron decay branching ratio obtained for the GDR in ^{48}Ca is found in a reasonable agreement with the corresponding experimental value deduced in [4] from ^{48}Ca (e, e'n)-reaction cross section.

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TRENDS IN MECHANISMS OF ^{9}Be(d,^{4}He)^{7}Li TRANSFER REACTION

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Theoretical analysis of ^{9}Be(d,^{4}He)^{7}Li transfer reaction at energies 7, 19.5, 25 and 35 MeV has been performed. The present work purpose is to enhance the theoretical description of the transfer reaction angular distribution, since a purely one step transfer mechanism is incapable to describe satisfactorily the experimental data. Drawing on the weakly bound neutron in ^{9}Be, it is proposed a treatment by including a two-step transfer process (d,t) $\rightarrow$ (t,^{4}He). A sequential endothermic transfer (d,^{3}He) $\rightarrow$ (^{3}He,^{4}He) and heavy ion transfer are also quite possible (see Fig. 1).

Experimental data have been analyzed by means of coupled reaction channels (CRC) calculations [1]. The channel coupling scheme adopted, including intermediate excited states, is shown in Fig. 1. A potential introduced in [2] has been used as optical potential of entrance channel, because it reflects real sizes of interaction and has been calculated within the double folding model. For other optical potentials the global parameterizations with slight reasonable modifications in the Woods-Saxon's potential form have been used. Overlap functions for one particle states have been calculated in the framework of realistic shell model [3].

Data used for CRC calculations and theoretical analysis of angular distributions for ^{9}Be(d,^{4}He)^{7}Li reaction at different energies are presented. It is established that generally sequential transfer of the deuteron is dominated.

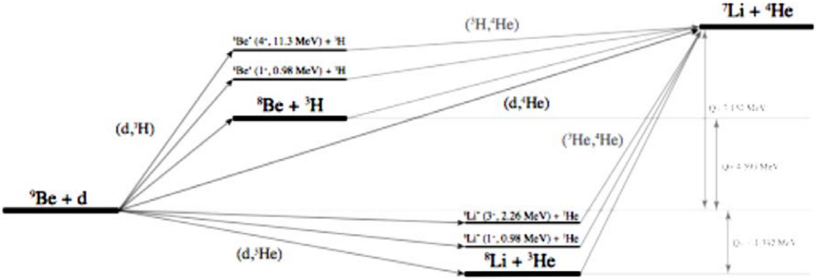

Fig. 1. Scheme of transfer mechanisms for channel coupling.

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ABOUT POSSIBILITY OF HEAVY MESON RESONANCES'S DISPLAY AT HIGH ENERGY ELASTIC NUCLEON-NUCLEON SCATTERING

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Proton-proton scattering from middle to super high energy has been studied previously [1, 2]. This consideration was based on the mathematical eikonal method [3] of the Lippman-Schwinger equation's solution for *T*-matrix that satisfies the unitarity conditions. It was shown that two singlet and triplet spin amplitudes take part in cross section of elastic scattering and their contributions to the differential cross section are different at variety values of the transfer momentum. The triplet amplitude is the row of odd order amplitudes in the partial wave analysis and evaluates the peripheral collision. It has the more spin statistic weight and takes the most part in the cone and the minimum region of the differential cross section. The singlet one contains the zero and even partial wave amplitudes. It encloses information about nucleon's structure by way of nucleon's form factor and virtual meson's interaction that described by the heave meson's resonances.

Possibility of the two spin amplitudes using for neutron-neutron, proton-neutron and also proton-antiproton elastic scattering definition is discussed in this report.

Derived differential cross sections for this reactions display that the above method describes the same effects as in p-p scattering, including the heave meson's resonances manifestation. This is the characteristic property of proton-antiproton elastic scattering. The proton-antiproton scattering triplet amplitude has the form of the singlet one for proton-proton scattering and the singlet proton-antiproton amplitude is as the triplet one in proton-proton scattering because exclusion principle.

The experimental investigation of polarized hadron's scattering will be very useful to define more exactly the above description.

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ELASTIC AND INELASTIC NUCLEONS AND ALPHA PARTICLES SCATTERING ON CLASTER'S NUCLEI IN SELF CONSISTENT METHOD OF THREE PARTICLES SCHRODINGER EQUATION'S SOLUTION

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The solution of the Schrodinger equation for problem of scattering particle on two-particles bound system in Jacoby coordinates

$$[-\frac{\hbar}{2M}\Delta_{\vec{R}} - \frac{\hbar}{2\mu}\Delta_{\vec{r}} + V_{12}(\vec{R},\vec{r}) + V_{13}(\vec{R},\vec{r}) + V_{23}(\vec{r})]\Psi(\vec{R},\vec{r}) = E\Psi(\vec{R},\vec{r}) \quad (1)$$

was found in the self-consistent method [1, 2] as

$$\Psi(\vec{R},\vec{r}) = (2\pi)^{-3/2} e^{if(\vec{R},\vec{r})}\Phi_s(\vec{r}). \quad (2)$$

In the equations (1, 2) $\vec{r}$ and $\vec{R}$ are the Jacoby coordinates of the relative motion of particles in pare (m_i, m_j) and third particle with the center of bound system mass accordingly. M is the three particles reduced mass and μ - the bound system reduced mass. $\Phi_s(\vec{r})$ is the normalized interne bound system's wave function by the energy E_s in asymptotic case ($\vec{R} \to \infty$), and $f(\vec{r},\vec{R})$ is real function that conserves the normalization of the wave function (2). After derivation to $\vec{r}$ the equation (1) has the form

$$[-\frac{\hbar}{2M}\Delta_{\vec{R}} + V(\vec{R},\vec{r})]\Psi(\vec{R},\vec{r}) = (E - E_s)\Psi(\vec{R},\vec{r}). \quad (3)$$

The complex potential $V(\vec{R},\vec{r})$ contains the information as about two-particle interactions so about the wave function of the bound system and in principle may depend on the energy. The function $f(\vec{r},\vec{R})$ can be expanded into series relative the coordinates of the vector $\vec{r}$ in the asymptotic. Coefficients of series are defined from the equation (3). The iterative convergence for the function $f(\vec{r},\vec{R})$ is in fact, because the real and imaginary parts of potential $V(\vec{r},\vec{R})$ are contained in each term of series in the power not more than one.

In this work we obtained the differential characteristics for elastic and inelastic protons and α-particle's scattering on light nucleus in three particle problem's frame with Gaussian potential and the final function of the bound system in some channels.

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MULTINUCLEON TRANSFER IN REACTIONS ^{40}Ca + ^{96}Zr, ^{40}Ca + ^{124}Sn, ^{40}Ca + ^{208}Pb

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Numerical solution of the time-dependent Schrödinger equation (TDSE) [1] is used for studying multi-neutron and multi-proton transfer processes in low-energy nucleus-nucleus collisions. The evolution of the wave functions for all nucleons is determined for reactions ^{40}Ca + ^{96}Zr, ^{40}Ca + ^{124}Sn, and ^{40}Ca + ^{208}Pb. An example of evolution of the probability density for all nucleons during the grazing collision of ^{40}Ca + ^{124}Sn is shown in Fig. 1. The transfer probabilities are calculated for external and deeper nucleon shells of the colliding nuclei. For the ^{40}Ca + ^{96}Zr reaction, the most probable transfer takes place for $2d_{5/2}$ neutron shell of the ^{96}Zr nucleus and $2d_{3/2}$ proton shell of the ^{40}Ca nucleus. The results of calculations of transfer cross sections are in satisfactory agreement with experimental data for reactions ^{40}Ca + ^{124}Sn [3] and ^{40}Ca + ^{208}Pb [4].

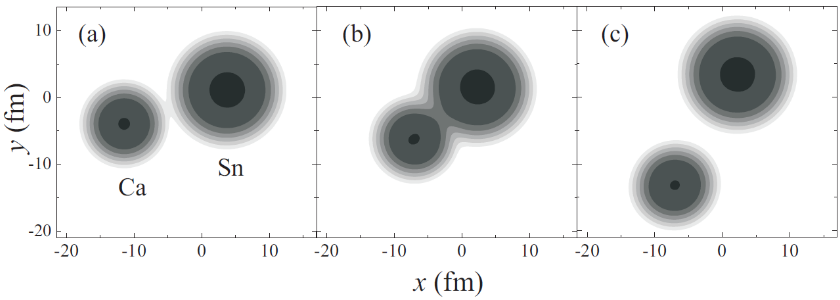

Fig. 1. Evolution of the probability density for all nucleons during the grazing collision of ^{40}Ca + ^{124}Sn at the center-of-mass energy 128.5 MeV and impact parameter b=4 fm. The sequence of figures (a, b, c) follows the timeline.

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FISSION RATES OF EXCITED NUCLEI: SPATIAL AND ENERGY DIFFUSION REGIMES

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The fission of excited nucleus is often considered as an escape of a Brownian particle from the metastable state under the influence of thermal fluctuations. Usually, to model numerically the thermal decay of a metastable state one uses different approaches for different ranges of friction constant [1–3]. We performed the numerical modeling of this process within the very same approach for all values of the friction coefficient, namely, using the Langevin equations [2, 4].

First, we compare in Fig. 1 the numerical quasistationary fission rates R_D with the analytical Kramers rates: R_{KM} for the case of middle and large friction (spatial diffusion regime) [1] and R_{KS} for relatively small friction (energy diffusion regime) [1, 5]. The transition state rate R_{TS} [6] is shown in the Fig. 1 as well.

Also, we analyze the influence of the descent stage of the potential on the quasistationary decay rate: as the friction coefficient decreases, this influence gradually disappears. It is found that, in the energy diffusion regime, the backscattering of Brownian particles absents and therefore the descent stage does not influence the decay rate.

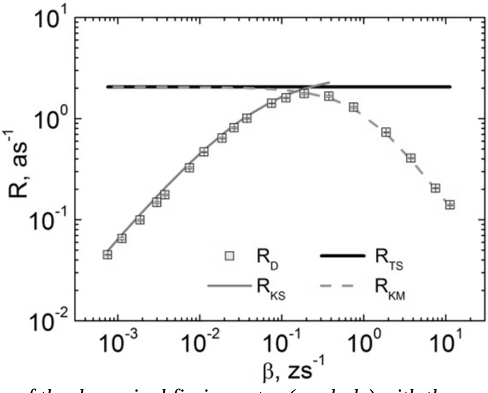

Fig. 1. Comparison of the dynamical fission rates (symbols) with the analytical ones (curves).

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SOLUTION OF SCATTERING AMPLITUDE FOR A FINITE REGION OF CALCULATIONS

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The two-dimensional or tree-dimensional scattering problem can be mainly solved by numerical methods. The most efficient use of computer resources is possible when a specific task can be complemented with the partial conditions of scattering. In more general than the partial condition case, a direct discretization of two-dimensional differential equation can be used, with subsequent application of the tridiagonal matrix algorithm. This algorithm has been successfully applied for the problem of two-dimensional scattering of rigid molecule [1] where the quantum angular momentum isn't conservative. The solution has been received over a wide range of energy.

One of the problems of this method is a need to calculate up to asymptotic distances which are significantly larger than the size of the scattering center r_c. In the cited paper the asymptotic distance is 100÷200 r_c. In the current work the possibility of reducing the asymptotic distance to a distance which is comparable with r_c has been investigated. To realize this additional decomposition of the solution by free equation wave functions has been made.

Software packages that include the algorithms of this report will be use for the problem of the nuclear particles scattering by non-spherical nuclei.

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EFFECT OF POLARIZATION PHENOMENA ON INTERACTION OF PROJECTILE WITH A SOLID TARGET

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In a number of current investigations within the scope of modern physics the time-resolved experiments play a central role in understanding of physical phenomena. As an important example, consider the particle-solid and particle-nucleus interaction physics. Although the standard scattering theory in principal can give us estimations of probabilities of transitions of the system to different conceivable final states, it cannot explain some important intermediate processes which can effectively change the expected results.

Calculation and further analysis of density matrix (DM) for projectile which collides with a solid film reveals some new representations which hard to be anticipated without the calculation. Namely:

1. The coherence properties in the projectile's wave field are describing through the special function of coherence [1]
$$f(\vec{x}_1,\vec{x}_2,t)=\frac{2\Gamma(\vec{x}_1,\vec{x}_2,t)}{\Gamma(\vec{x}_1,\vec{x}_1,t)+\Gamma(\vec{x}_2,\vec{x}_2,t)},$$
where $\Gamma(\vec{x}_1,\vec{x}_2,t)$ – density matrix of the projectile depending on two spatial points $\vec{x}_1,\vec{x}_2$ and the time *t*.
2. The collision with solid leads to a significant decrease in the total coherence length of projectile's wave field. The coherence length can become much smaller than the initial size of wave field of the projectile.
3. During the collision with solid the number of different spatial areas where the mutual coherence in the projectile's wave field is supported, can be multiplied.
4. The every part of projectile's wave field can be individualizing as the separate particle having own property in its inner quantum state. The procedure which has a responsibility for such a transformation can be characterized as the spontaneous breaking of symmetry.
5. The process described in the point 3 can be considered as a special form of breaking in quantum mechanics.
6. The parts of the wave field considered above can be stabilized in its quantum state after been captured in its own polarization well.

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INTERACTION OF $\pi^{\pm}$- AND K^{+}-MESONS WITH $^{13,15}C$, ^{15}N NUCLEI AT INTERMEDIATE ENERGIES IN THE GLAUBER THEORY

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The processes of mesons interaction with nuclei at intermediate energies can be studied with nearly equal success in the framework of the optical model, in the impulse approximation with distorted waves, by the method of coupled channels, in the Glauber's theory of diffraction scattering and others. The latter is a very convenient and realistic model for investigating many effects: multiple scattering on the nucleus nucleon in the elastic and inelastic channels, quasi-elastic knockout, nuclear correlations, channels coupling, etc. The Glauber's theory is attractive since it enables us to separate the structural (depending on the wave functions (WF) of the target nucleus) and dynamic components (depending on the multiple scattering operator) of the scattering amplitude. The input parameters of the theory are WFs of target nuclei and elementary nucleon-meson amplitudes.

An analysis of elementary nucleon-meson amplitudes at the quark level made it possible to compare different types of particles interacting with nucleons: protons, $\pi^{\pm}$ and K^{+} mesons.

This paper jointly reviews the scattering of $\pi^{\pm}$ and K^{+} mesons on $^{13,15}C$, ^{15}N nuclei with WF in the shell model in the framework of the diffraction theory. The application of the Glauber's theory enabled us to analyze the scattering processes microscopically, i.e. to calculate the contributions of different scattering multiplicities in the operator Ω to the differential cross section and the dependence of the characteristics on the energy of the scattered particles.

It is shown that in the calculations of the cross sections with $\pi^{\pm}$-mesons on nuclei, it is necessary to take into account all multiplicities of scattering and re-scattering in the operator Ω to describe the differential cross sections over a wide angular range, whereas for K^{+} mesons we can be limited by one- and two-time collisions, since the series of multiple scattering agrees rapidly.

Comparison of scatterings on the same target nuclei of different particles is of special interest, since the particles of various nature interact differently with the nucleus nucleons and the features of their interaction will be displayed in the observed characteristics. Thus, the strong absorption of $\pi^{\pm}$-mesons in the Δ-resonance region makes it possible to study the periphery of nucleus with their help, whereas the K^{+} mesons are absorbed weakly, which makes it possible to use them as a probe for studying the inner region of the nucleus.

TECHNIQUE AND METHODS OF EXPERIMENT AND APPLICATIONS OF NUCLEAR-PHYSICAL METHODS

FORMATION OF OXIDE NANOSTRUCTURES ON THE SURFACE OF RADIATION-OXIDATED ALUMINUM

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Reflection IR spectroscopy, atomic force microscopy (AGM), and electrophysical measurements were used to perform a complex study of the formation of surface oxide nanostructures during the radiation oxidation of metallic aluminum in contact with water at room temperature. The dynamics of formation of oxide nanolayers was controlled by the change in the absorption band of the valence vibration of the Al-O bond (ν = 950 cm^{-1}) as a function of the time of contact of aluminum with water from 5 minutes to 18 hours.

The initial surfaces of aluminum plates and changes occurring on the surface of these samples after radiation treatment at room temperature under the influence of gamma quanta are traced on an atomic force microscope. Three-dimensional (3*d*) surface AGM images and histograms were obtained in order to reveal the dynamics of morphological changes in the surface before and after radiation oxidation. As demonstrated by AGM studies, the radiation modification of the surface relief is accompanied by the formation of oxide nanostructures, the defectiveness of which is determined by the irradiation time.

On the basis of electrophysical measurements, in particular, according to the logarithmic dose dependence of the surface resistivity of aluminum, a three-stage oxidation process in the region of absorbed dose (0.5 – 120 kGy) was revealed. It is shown that the transition from the first stage to the third is accompanied by a decrease in the electrical conductivity by 5 orders of magnitude and an increase in the thickness of the oxide nano layer by an order of magnitude (from 8 to 250 nm). The role of surface relaxing intermediate-active particles in the dynamics of formation of oxide nanostructures is considered.

LONGEVITY STUDIES OF MULTIWIRE PROPORTIONAL CHAMBERS OF THE CMS EXPERIMENT AT THE LHC

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Degradation of multiwire proportional chambers (MWPC) remains a problem in high energy physics experiments with high radiation background as like at the Large Hadrons Collider (LHC) in CERN. This problem will be especially actual for CMS experiment, with start of the High Luminosity LHC project in 2025 ($L = 5\times10^{34}$ cm^{-2}s^{-1}).

The CMS muon detector uses Cathode Strip Chambers (CSC) in the end cap regions to obtain a precise measurement of the position and thus the momentum of the muons. CSC consists of anode wires plane crossed with negatively charged copper strips (cathode) within a gas volume (40%Ar + 50%CO_2 + 10%CF_4). The wires give the radial coordinate and the strips measure azimuthal angle. The results of the CSC prototype longevity evaluation with local fast aging test are presented in Fig. 1, left panel. One can see that gas gain (M/M_{ref}) in arbitrary units is stable both for irradiated (E) and not irradiated (D, F) anode wire zones at accumulated dose 1.36 C/cm. That is equal to ~30 HL LHC operation years.

Next challenge for the CSC performance is ecology. Recent regulations demand the use of environmentally unfriendly Freon-based gases to be limited or banned. Therefore, since of 2026 the emission of greenhouse Freon CF_4 into the atmosphere have to be reduced. As a possible solution a working gas mixture 36.6%Ar + 61.7%CO_2 + 1.7%CF_4 with 5 times smaller content of CF_4 have been tested by the CSC prototype. Fig.1, right panel, shows results of another local fast aging test with new gas mixture. Gas gain stay stable up to accumulated dose of 0.39 C/cm, that is sufficient to 7 years operation at HL LHC conditions.

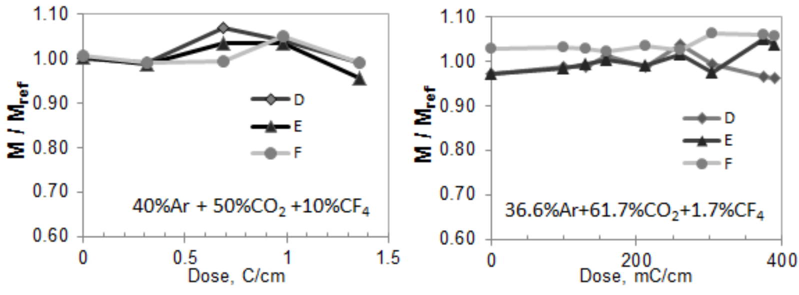

Fig. 1. Fast CSC aging test results with working gas mixture (left) and with a gas mixture containing 5 times smaller amount of CF_4 (right).

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INVESTIGATION OF THE PHYSICAL PROPERTIES OF GAS-DISCHARGE PARTICLE DETECTORS USING THE MONTE CARLO METHOD

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As members of the St.Petersburg Institute of Nuclear Physics (department of the track detectors) we are working on the development of a new gas-discharge chamber in close cooperation with the scientists from GSI (Darmstadt, Germany).

Our department takes a part in the international R3B collaboration. For the R3B experiment, the Detector System PAS (Proton Arm Spectrometer) is developed in the Department of Track Detectors of the Division of High Energy Physics.

Simulation of the experiment on the interaction of a proton beam with PAS assembly materials using the GEANT4 software package will include:

1) determination of the coordinates of particles recorded in the volume of the detector;

2) track analysis of the detected particles; determination of the track length and the mean free path of the particles in the material; calculation of the deflection angle of the particles from the initial direction and the divergence of the entire proton beam;

3) time characteristics determination of the prototype detector;

4) proton energy losses determination;

5) identification of other particles (heavy ions) formed as a result of the nuclear reaction;

6) interaction cross sections calculation of the detected particles with matter;

7) determination of the number of particles recorded at the output.

The first results obtained showing the energy losses in the volume of the detector at different values of the wall thickness of the tube and various cathode materials, as well as the angular distribution of the particles as they pass through each of the recording planes[1, 2].

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INVESTIGATION OF FULLERENOLS AND ENDOFULLERENOLS SELF-ASSEMBLY IN AQUEOUS SOLUTIONS BY THE NUCLEAR PHYSICS METHODS

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Biomedical applications of fullerenes come from their unique structure and physicochemical properties diversified in derivatives. Recently at PNPI there were synthesized and investigated new endofullerenes capturing paramagnetic atoms of 4*f*-metals (from praseodymium to thulium, atomic numbers $Z = 59–69$) for topic applications as contrast agents in Magneto-Resonance Imaging or carriers of nuclear isotopes. It was very important to conduct a comprehensive analysis of their water-soluble forms' behaviors in solutions under particular conditions (temperature, concentration, pH-factor) existing in living organisms. It becomes possible due to nuclear physics methods such as small-angle Scattering, Magneto-Resonance Imaging and others.

Here we presented the results of systematic structural analysis of water-soluble derivatives of fullerenes and endofullerenes in aqueous solutions. Hydroxyl derivatives of fullerenes $C_{60}(OH)_{30}$ and $C_{70}(OH)_{30}$ and endohedral fullerenes with rare earth elements have been studied by small-angle neutron and *X*-ray scattering, dynamic light scattering as well as by atomic force microscopy. In aqueous solutions their three-level structural organization was detected as dependent on the concentrations and pH-factor. There were observed various forms of fullerenols and endofullerenols self-assembly that includes tiny molecular groups of molecular size integrated into more extended aggregates and superstructures in the range of ~1–100 nm (aggregation numbers $\leq 10^4$). The analysis of the influence of external and internal parameters allowed formulating physical criteria of solutions stability and qualitative differences for fullerenols and endofullerolenols systems. The magnetic and electric dipole moments induce dipole-dipole interactions which contribute to more densely packing the endofullerenols molecules in globular aggregates. The obtained structural results possess an undoubted practical importance assuming the prospects of biomedical applications of fullerenes and their water-soluble derivatives.

CHANGES IN CHARACTERISTICS OF BONE GRAFTS DURING RADIATION STERILIZATION

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Radiation sterilization of bone implants is now a common technology of their finishing treatment for preservation for some time before clinical use [1]. However, significant doses required to ensure high – quality sterilization (standard, confirmed by the IAEA recommendations 25 kGy), can lead to significant changes in the characteristics of bioimplants [2, 3]. At low (up to 5 kGy) doses, there are no significant deviations from the native values, and with an increase in the dose to 25 kGy and further to 50 kGy bending strength decreases by almost a third. In addition at doses from 15 kGy there are changes in the morphology of samples, for example, swelling and separation of collagen fibers [2] and the standard dose exceeding leads to destruction of morphogenetic proteins.

Moreover, these changes substantially depend on the chosen order of procedures sample handling (freezing, lyophilization, ozone treatment, radiation exposure). This circumstance allows us to develop effective technologies of combined sterilization with a significant reduction of radiation exposure [4]. This technology is based on synergetic effects of combined action of physical-chemical sterilization factors of different nature (chemical treaty by ozone-oxygen mixture and radiation processing by fast electrons) on bone grafts.

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PRODUCTION AND THERMOCHROMATOGRAPHIC SEPARATION OF NO-CARRIER-ADDED ^{90}Nb VIA ^{93}Nb(p,4n)^{90}Mo

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In recent years, a lot of research has been performed to expand available radionuclides for immuno-PET diagnostics with ^{64}Cu, ^{86}Y, ^{76}Br, ^{89}Zr, ^{124}I. Another one promising radionuclide is ^{90}Nb because of its suitable characteristics: a half-life of 14.6 hours, a relative fraction of β^+-radiation of 53%, an average energy of β^+ radiation of 350 keV [1]. An important task is to develop an express method for obtaining ^{90}Nb radionuclide without a carrier.

Here we report an original method for isolating ^{90}Nb ($T_{1/2}$ = 14.6 h) produced in ^{93}Nb(p,4n)^{90}Mo reaction via β^+-decay of ^{90}Mo ($T_{1/2}$ = 5.7 h). Niobium target was irradiated with 65 MeV protons. The separation of ^{90}Mo from the irradiated target was carried out in a high-temperature tubular furnace. The thermochromatographic method provides a high yield of the mother radionuclide ^{90}Mo for accumulation ^{90}Nb.

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IR-SPECTROSCOPIC STUDY OF NANO-ZrO_2 + NANO-Al_2O_3 SYSTEMS UNDER THE INFLUENCE OF GAMMA IRRADIATION

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Nanosized aluminum and zirconium oxide compounds are widely used as active components and an effective carrier of catalysts in various processes, including radiation-catalytic processes of hydrogen production from water [1 – 6]. Zirconium and aluminum oxides are also technologically important materials in the field of manufacturing ceramics, solid electrolytes, radiation detectors and materials for space and nuclear technologies. As you know, reducing the particle size to nanoscale, leads to a significant change in physical properties [3 – 4]. The dimensions of the individual nanoparticle particles are comparable to the mean free path of electrons, holes, and excited states produced by the action of ionizing radiation, which takes place in the effective transformation and transfer of energy, as well as the detection of active particles.

As a result of the interaction between the components, the concentration of surface acceptor centers changes, as well as the mechanical and physical properties of the components of the system. Information on the effect of the second component on the surface physico-chemical and radiation-catalytic properties of the binary system of nano-ZrO_2 + nano-Al_2O_3 + H_2O is limited. In the literature there is virtually no spectroscopic data on the radiative decomposition of water in a mixture of nano-ZrO_2 + nano-Al_2O_3 + H_2O.

The radiation-thermal decomposition of water in the nano-ZrO_2 + nano-Al_2O_3 + H_2O heterosystem in the temperature range 373 – 673 K at the ratio of nanooxides (3:1, 1:1 and 1:3) was studied by Fourier-IR spectroscopy and at a fixed value of the absorbed dose ($D_\gamma = 30$ kGy). It is shown that the adsorption of water in a mixture of nano-oxides of zirconium and aluminum occurs by molecular and dissociative mechanisms.

The intermediate products of the radiation-heterogeneous decomposition of water are ion-radicals of molecular oxygen, surface hydrides of zirconium and aluminum, as well as hydroxyl groups. Dependences of the intensities of absorption bands of molecular water and surface hydrogen-bonded and isolated hydroxyl groups characterizing nano-ZrO_2 and nano-Al_2O_3 on temperature have been studied. Based on a comparative analysis of these relationships, the radiation-catalytic activity of nano-ZrO_2 in the radiation-thermal process of water decomposition has been revealed.

THE STUDY OF THE MECHANISM OF WATER ADSORPTION ON THE SURFACE OF NANO-Zr BY IR SPECTROSCOPY

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Fourier IR absorption spectra were recorded on a Varian 640 FT-IR spectrometer in the frequency range $\nu = 4000 - 400$ cm^{-1} at room temperature. To remove the absorption spectra, zirconium nanopowders were compressed into tablets with a thickness of 50 – 100 μm.

In the IR absorption spectra of nano-Zr samples with adsorbed water, a wide band with a maximum of 3300 cm^{-1} is observed in the valence OH groups and water region ($\nu = 4000 - 3000$ cm^{-1}), which refers to adsorbed water molecules at $T = 300$ K. A broad band with a maximum at 1630 cm^{-1} also appears in the region of deformation vibrations of adsorbed H_2O molecules.

Radiation-thermal decomposition of water at $T = 373$ K is accompanied by a decrease in the intensities of the molecular water band in the regions of valence and deformation vibrations of H_2O. An increase in the temperature to 473 K decreases the intensity of the band of H_2O molecules and is accompanied by the formation of a series of AB hydrogen-bonded hydroxyl groups at 3580 and 3450 cm^{-1}.

RANDOM COINCIDENCES OF EMPIRICAL DISTRIBUTION VECTORS OF EVENT FLOW COUNTS

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A mechanism is suggested for stochastic, almost synchronous formation of identical empirical vectors of distribution series of counts of $K(\Delta t)$ particles over time intervals Δt of independent radiation flows. If the sequence of points of time t_i of particles registration conforms with a stationary Poisson process, and the respective sequence $K(\Delta t)$ conforms with the Poisson distribution, then the distribution of the empirical vector $(n_0,...,n_l)_j$, where $n_{ij}(K(\Delta t)=i)\geq 0$, $n=\sum_{i=0}^{l} n_{ij}$ for the sample $K(\Delta t)$ of volume n and of duration $\theta = n\Delta t$, where $j-$is a unique vector type, conforms with the binomial distribution and approximates well with the Poisson distribution [1]. Distribution of intervals $r_j = r((n_0,...,n_l)_j)$ between identical vectors is governed the geometric distribution, and at the average value of $\overline{r_j} \gg 1$ also to the one exponential over the time scale $\overline{\theta}_j = \overline{r}_j\theta = \overline{r}_j n\Delta t,$ where $\overline{r}_j = 1/P_j - 1,$ P_j is a polynomial probability of formation of vector [1]. At coinciding or close values of $\overline{\theta}$ $\overline{K}(\Delta t) = \nu\Delta t,$ where ν is the radiation intensity for some independent sequences $\{t_i\}$, $\{K_i(\Delta t)\}$, $\{(n_{ij})_l\}$, the distribution of intervals r_j between the identical vectors $(n_{i,j})_l$ of two different sequences conforms with the geometric distribution (at $\overline{r_j} \gg 1$ with the exponential one) with the parameter $\overline{r}_{j,1,2} = (1/\overline{r}_{j,1} + 1/\overline{r}_{j,2})^{-1}$, where $\overline{r}_{j,1,2}$ – the means of flows 1 and 2 being compares, and at $\overline{r}_{j,1} \simeq \overline{r}_{j,2}$, $\overline{r}_{j,1,2} = \overline{r}_j/2$ [2]. Therefore, similar to the delayed coincidences, there occur, with high probability, almost synchronously, the identical empirical vectors – distributions of counts of various flows. The suggested stochastic mechanism of random delayed coincidences of the Poisson sequences, of identical or almost similar (by some criterion) vectors $(n_{i,j})_l$ of uncorrelated flows of different radiations, does not depend on the external synchronization factors, distances between the radiation sources and the registering devices, as well as on the shift in time of obtaining each of the sequences $(n_{i,j})_l$, in contrast to [3].

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THE IMPACT OF 1 MeV ELECTRON BEAM ON MICROBIOLOGICAL PARAMETERS OF CHILLED TROUT

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The accelerated electrons and gamma radiation are applied for processing of foodstuffs to extend their shelf life. The treatment on dried fish is carried out at irradiation doses from 0.1 to 1.0 kGy. Fresh fish is treated at irradiation doses from 1 to 7 kGy to decrease the development of pathogenic microorganisms, bacteria (coliforms, salmonella) and parasites [1]. Radiation of gutted fish and further storage at 2–3°C allows increasing the period of storage up to 14 days. [2].

This study illustrates the impact of 1 MeV electrons at different doses on bacteria quantity in chilled trout. Firstly, fish mince and a suspension of bacteria were prepared. Then the mince was placed in sterile test tubes. Secondly, the tubes were irradiated with doses 150 Gy, 1 kGy, 5 kGy using the industrial electron accelerator UELR-1-25-T-001. Finally, the amount of mesophilic aerobic and facultative anaerobic microorganisms (CFU/g) in irradiated and nonirradiated samples was measured.

It was determined that the irradiation of fish mince led to a significant decrease in bacteria quantity in it. According to the international standards the acceptable level of bacteria in fish products is less than 10^5 CFU/g. The amounts of bacteria (CFU/g) in treated samples were $0.9352 \cdot 10^4$, $0.1376 \cdot 10^4$, $0.0204 \cdot 10^4$ at irradiated doses 150 Gy, 1 kGy, 5 kGy correspondently. The amount of bacteria (CFU/g) in nonirradiated samples was $1.2 \cdot 10^4$.

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RADIATION RESISTANCE OF THE POLYMER MATERIAL UNDER NEUTRON IRRADIATION

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A test of the radiation resistance of a polymer material in a fast neutron flux in a RADEX irradiator was carried out. The main operating parameters of the pulsed neutron source were: fast neutron energy from 0.1 to 14 MeV, neutron flux density of about 10^{13} n/cm^2/s, pulse duration 0.3–200 μs.

Polymeric materials are used in structural products in conditions of cosmic or technogenic radiation of radiation objects. For example, when operating a material in a spacecraft for 20 years, the radiation dose can reach 10^5 Gy.

The radiation resistance of a specimen of an organic glass of cylindrical shape 10 cm high with an average fast neutron flux per sample of about 10^{10} n/cm^2/s was investigated. This corresponds to an average radiation dose rate of 1 Gy/s. Inside the cylinder was an activation sample of ytterbium-168 for measuring the fluence of neutrons and the average absorbed dose of neutrons by the activation method.

At weekly irradiation, the integral absorbed dose at the center of the sample was about 10^6 Gy. For the lower part of the organic sample, the radiation dose was an order of magnitude higher, which caused numerous fractures and cracks in the sample. In the upper part of the cylindrical sample, the fast neutron flux was significantly smaller due to the slowing down and absorption of neutrons. The uneven distribution of the fast neutron flux created an unequal radiation effect on the organic material, which caused its non-uniform damage.

DISTRIBUTION OF DT NEUTRONS IN THE COMBINED MODERATOR

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The results of calculations and experimental measurements of the flux density of slowing down DT-neutrons in a combined moderator with elements of tungsten, lead, beryllium, polyethylene, graphite and water are presented. The calculations were performed by the Monte Carlo method for a moderator containing a converter, a reflector, and a cavity for activating the samples in neutron radiation capture.

The source of fast neutrons with an energy of 14–15 MeV was located between the reflector and the converter from Be, W and Pb, behind which was a slowing block. Fast neutrons from the source multiplied in the converter due to the (n, 2n) reaction, losing their energy to 1–4 MeV in inelastic scattering, then slowed down by a block of polyethylene, graphite or water. A reflector made of lead or beryllium created an additional neutron flux.

The optimum parameters of the moderator at the maximum thermal neutron flux density were obtained with a converter thickness of about 10 cm, reflector thickness of about 20 cm and a size of the slowing block $\geq 30\times30\times30$ cm^3. The maximum flux of thermal neutrons was obtained at a depth of 5 cm in the polyethylene slowing block and 30 cm in the graphite block. For W converter, the flux density of thermal and fast neutrons per 1 neutron of the source was $2\cdot10^{-3}$ $n/cm^2/s$ and $0.1\cdot10^{-3}$ $n/cm^2/s$ respectively, for the polyethylene block and $4\cdot10^{-4}$ $n/cm^2/s$ and $0.04\cdot10^{-4}$ $n/cm^2/s$ for graphite.

In measurements, the W-polyethylene moderator made was placed near the tritium target of the NG-400 neutron generator with a DT neutron intensity of 10^{11} n/s. The neutron flux density measured by the activation method in the cavity of the block at a depth of 5 cm with the help of Mn, Nb and In samples was $1.5\cdot10^8$ $n/cm^2/s$ for thermal and $0.2\cdot10^8$ $n/cm^2/s$ for fast neutrons, respectively.

ELECTRONIC PROCESSES OCCURING IN GaSYb MONOCRYSTAL WITH IRRADIATED HIGH-ENERGY RAYS

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In recent years, intensive development of nuclear physics, photoelectronics and space research aims the opportunities of new physical properties and the preparation of new functional devices based on them in front of semiconductors. For this reason, study of the physical properties of monocrystals taken on the basis of $A^{III} B^{VI}$ binary systems with additive atoms, the effects of ionizing rays is great importance to the scientific point. For this purpose, GaS monocrystals with doped itterbium have been used in the study. Samples obtained by Bridjmen at the room temperature, have been irradiated in the ^{60}Co device with energy of 1.33 MeV, special resistance has been compiling ~10^5 Om·cm at the room temperature. Contacts have been shot in the perpendicular direction to the layers with silver paste.

The dependence of photoconductivity of illuminated GaSYb monocrystal with a light the specific absorption line (λ=0.59 nm) on temperature has been studied in the study. The price of photoconductivity remains practically constant with increasing temperature (T=100 K÷140 K). The price of photoconductivity is increasing exponentially at various doses (D=20 krad, 50 krad) starting at T_2=140 K. The activity of the photocurrent ends for all irradiation rates at the same temperature (T_1=435 K). After the temperature T_1=435 K, it is observed extinguishing of photocurrent. The appropriate bending point at T=140 K slides towards the high temperature zone depending on the radiation dose. Dependency of lgΔJ from ($1/T_2$) is 0.35 eV.

It can not be explain obtained ΔJ (T) dependence by varying the mobility of carriers depending on the temperature, because mobility varies with T^{-2} law in that temperature region [1, 2]. The activity of photocaration can be explained within a three-level model for monopoly semiconductors [3]. Thus, the fast *s*, slow *r*-recombination centers, also playing the role of retention *t*-level for main carriers. The retention level causes activation of photocurrent, while *r*- center causes temperature drops. The main carriers eclipse have been observed only at certain temperature ranges and lighting of crystal. The following parameters have been set for the presented crystal. Distance from retention level to valence zone E_{vt}=0.30 eV, the distance from recombination center to conductive zone E_{cr} = 0.52 eV, concentration $N_t = 2.5 \cdot 10^{12}$ cm^{-3}.

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STUDY OF THE HYPERFINE INTERACTION DEPENDENCE ON THE CRYSTALLITE SIZE AND APPLIED TEMPERATURE IN $CoFe_2O_4$ BY γγ-TDPAC

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Spinel ferrites (including $CoFe_2O_4$) are mainly used because of their ferrimagnetic properties (i.e. as memory storage devices). In recent years, they are expected to acquire new broad application for catalysts preparation: a) based on their own catalytic properties or b) by combining them with other catalysts in nanocomposites of the type «core/shell». The ferrimagnetic properties of the ferrites are essential for both types of catalysts, because it allows easy separation of the catalyst from the reaction mixture and their further recycling. The general rule is that with the reduction of crystallite size, the catalytic activity of the ferrites increases but at the same time decreases the magnetic susceptibility. In the case of gas-solid heterogeneous catalytic reactions which generally occur at high temperatures (200 – 800°C), an important characteristic becomes the Neel temperature.

In this paper, a study of the magnetic hyperfine interaction in cobalt ferrite samples of different crystallite size is performed using the γγ-TDPAC method using ^{111}In (^{111}Cd) as probe nucleus.

The γγ-TDPAC method is based on the introduction of a radioactive isotope (the probe-111In) into the sample, the decay of which is accompanied by the emission of cascade γ-quanta. The angular distribution of the emitted cascade γ-quanta provides information on the hyperfine fields with which the sample affects on the embedded nuclei.

The studied samples ($CoFe_2O_4$) were synthesized using epoxide sol-gel method and the radioactive isotope (^{111}In) was added during the synthetic procedure. The crystallite size was varied by preparing the samples using different annealing temperature. The different samples were investigated at room and high temperature and *as prepared* (amorphous) sample was measured *in situ* while gradually raising the temperature from room temperature to 775°C.

We observed unambiguous dependence of the magnetic hyperfine interaction from the crystallite size and disappearance of the magnetic hyperfine interaction above Neel temperature.

DOSIMETER OF IONIZING RADIATION

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The work of the semiconductor dosimeter with MOS structure as a sensor is based on a change in the threshold voltage value as result of the accumulation of a radiation-induced positive charge in the subgate oxide.

To measure the dose, the sensor is located and maintained the required time in the test field. The information about the exposure dose is removed from the change in the threshold voltage under the action of ionizing radiation.

The main “bottleneck” of the work of such dosimeters is their preparation for work, including “zeroing”, i.e. erasure of previously accumulated information.

The efficiency of using for this purpose the illumination of the sensor of the dosimeter by quanta of near-UV radiation was shown. It is established that the erasure from the sensor of the previously accumulated information is caused by the photoemission of electrons into the subgate oxide from the electrodes of the gate and the substrate. This leads to electroneutralization of the radiation-induced charge in the subgate oxide, as a result of which the threshold voltage returns to its initial value.

The UV-radiation quanta range for the “zeroing” operation was determined. The lower limit of UV irradiation is equal to 4.35 eV being that quanta with lower energies are insufficient to ensure photoemission of electrons and their entry into the subgate oxide. Quanta with energies above 8.8 eV cause undesirable generation of electron-hole pairs in the oxide, which leads to the accumulation of a radiation-induced charge. That is to say the same effect is observed as when exposing the sensor in the ionizing radiation field. The quartz window in the sensor body ensures the passage of the beam of UV quanta in the indicated energy range.

The proposed solution improves the operational characteristics of the dosimeter allows significantly improving the reliability and the life of the sensor. Multiple measurements with erasure of accumulated information do not affect the operability of the device and consist only in short-term irradiation of the sensor under the UV beam.

1. A.C. USSR №849871. cl. G 01 T 1/02. 1980

THE USAGE OF THE MOS STRUCTURE AS A SENSITIVE ELEMENT OF UV-DOSIMETER

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The dosimeter with the detector based on the MOS structure was designed for individual monitoring of the small doses of the UV radiation. The device has a high detector sensitivity, autonomy of work, small dimensions, a sufficiently long service life and low cost.

The physical basis for the development was the presence of two types of trap levels in the subgate oxide of the MOS structure. The shallow traps are associated with oxide defects and can be annealed in the operating temperature range (up to 150°C). Deep traps associated with impurities of phosphorus atoms in the oxide isomorphically substituting silicon in the SiO_2 grid nodes. They are not annealed by thermal influences up to maximum operating temperatures, which do not destroy the structure.

Irradiation under high temperature conditions results in the accumulation of the thermostable radiation-induced charge on deep traps. At the same time, the dielectric is freed from the charge generated at shallow trap levels.

The linear character of the thermostable, radiation-induced measurement of the MOST threshold voltage as a function of the dose of the implanted phosphorus in the subgate oxide is shown. Dependences of the change U_{thr} in the MOS structure, subjected to the radiation-thermal treatment, on the duration of the subsequent exposure to UV are obtained. The effectiveness of UV irradiation of the MOS structure depends on the ratio of the gate area to its perimeter, which indicates the peripheral character of the process. Parameters of the MOS structure of the gate sensor: length 10 μm, width 4000 μm; the oxide thickness is 0.98 μm.

The charge ("zeroing" of the device) was carried out by soft *X*-ray radiation with a photon energy of 20–30 keV at a temperature of 100–150°C and a dose of $5{\cdot}10^4$ – 10^5 R. The range of controlled UV radiation was from 4 – 6.8 eV (180 – 310 nm).

The dose of UV radiation was monitored by changing the threshold voltage of a pre-irradiated *X*-ray sensor.

LOW NEUTRON FLUX MEASUREMENTS IN UNDERGROUND LABORATORY IN MODANE USING IODINE-CONTAINING SCINTILLATORS

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This work presents results of measurements of neutron flux in the LSM underground laboratory with new highly sensitive method for the detection of neutrons developed in our group [1]. The method uses the $T_{1/2}$ = 845 ns delay in the decay of ^{128}I at the 137.8 keV energy level, resulting from the capture of thermal neutrons by iodine nuclei in NaI(Tl) scintillation detector. Since accidental background is almost quadratically proportional to the overall background signal the use of delayed coincidence techniques with a several μs delay time window for delayed events allows for the highly effective discrimination of neutron events from any existing background signals.

First measurements in the LSM underground laboratory with the proposed method were started in April of 2017 with 720 grams NaI(Tl) scintillation detector (Ø 63 mm × 63 mm). Two low background proportional ^{3}He counters [2] have been used for verification of the obtained results. After 241.84 days of measurements 67 delayed events were detected in the region of interest (137.8 keV energy) for prompt-delay time window 1.8–5 μs. The calculated background for above selection criteria is 31.809(2) events (mainly due to internal potassium content of the detector) agrees well with 35 events found in the shifted delay time window between 11.8 and 15 μs. Neutron events are the excess in 0.15(3) counts per day above the background. The resulting thermal neutron flux is $2.3 \pm 0.5 \times 10^{-6}$ n· cm^{-2} ·sec^{-1}. This value was found to be in the excellent agreement with neutron fluxes in 2.3×10^{-6} n·cm^{-2}·sec^{-1} and 3.1×10^{-6} n·cm^{-2}·sec^{-1} measured by ^{3}He detectors one placed near the lead shield of the setup and second one near the wall of the laboratory.

Performed measurements experimentally demonstrated the efficacy of the proposed detection method for low neutron fluxes. In future, the method can provide low-background experiments, using NaI or CsI, with measurements of the rate and stability of incoming neutron flux to a greater accuracy than 10^{-8} n·cm^{-2}·s^{-1}.

The work was supported by RFBR grant N 18-02-00159 A.

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STUDYING THE POSSIBILITIES OF COMPTON TOMOGRAPHY VIA SIMULATION

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Compton tomography (CT), the principles of which were justified about 30 years ago, is of genuine interest to researchers at present, in view of possible advantages in comparison with other types of transmission tomography. The main advantage of CT is the possibility of using a fixed detection system with a fixed source to obtain 3D images, or using a dynamic source-detector circuit for a stationary object. This creates a number of advantages both in the medical use of CT and for introscopy in general. The principle of obtaining information is based on the fact that the scattering angle in Compton scattering is rigidly related to the energy of the secondary gamma quantum, and measuring the energy spectrum allows us to reconstruct a spatial picture of the distribution of the electron density in matter. But the creation of Compton scanners requires careful study of all the elements of the scanner, starting from a monochromatic gamma source and ending with the requirements for the number and dimensions of the detectors, their resolving power. This work is devoted to the creation of simulation tools for obtaining reconstructed images of the objects under investigation. There are variants of different gamma-energy energies, changes in the position of the "source-object-detector". This work is devoted to the creation of simulation tools for obtaining reconstructed images of the objects under investigation. There are variants of different gamma-energy energies, changes in the position of the source-object-detector. The investigated object was assumed inhomogeneous and the quality of the created simulation tools was verified by comparing the test calculations with the results of calculations of other authors. The created simulation tools allow defining:

1. the most effective gamma source for a particular object;
2. range of scattering angles, which gives the most reliable result when restoring images;
3. number and resolution of detectors.

The results of the simulation are also distortions of visual information, arising due to the presence of a background, not Compton interactions in the object of the study, multiple Compton scattering, the efficiency of the detectors. A comparison with the results of [1, 2] allows to make the conclusion that the developed simulation tools adequately reflect the real scheme of CT operation.

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STUDY OF THE POSSIBILITY OF USING VARIOUS AEROSOL FILTERS IN NEUTRON ACTIVATION ANALYSIS

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To analyze atmospheric aerosols and precipitations their sampling on special analytical filtering materials both near the earth's surface and at different altitudes is performed. The composition and content of non-radioactive elements in the samples was determined by neutron activation analysis.

To select the analytical filtering sampling materials suitable for neutron activation analysis, we have considered the samples of different fibrous filter materials: filters of quartz fiber and fiberglass, bleached gauze, filters of LFS-2 type and filtering materials such as FPP (Petryanov's filtering cloth) of two kinds.

Analysis of activation gamma spectra corresponding to samples from different filter materials indicates the presence of traces of K, Na, Cl and Mn in the samples (in various combinations). The most suitable for neutron activation analysis is the quartz fiber filter. The limits of detecting microimpurities in materials are estimated.

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RESEARCHING THE SYNERGETIC EFFECT USING A RADIOACTIVE BEAM IN MEDICINE VIA STATISTICAL SIMULATION

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Radiation therapy of heavy charged particles (THCP) is one of the most effective methods of treatment of oncological diseases. This is explained by the possibility of targeted delivery of the therapeutic dose due to the presence of the Bragg peak, a narrow region in which more than 60% of the energy lost is concentrated. Although the centers of proton therapy have become most widespread, there are also ^{12}C ion beam therapies in the world. In the work, the joint effect of radioactive THCP beams on tumor tissues was analyzed, resulting from ionization upon irradiation and further decay of radioactive nuclei. This leads to a peculiar combination of THCP and brachytherapy [1]. The prolonged radiation effect during decay can significantly increase the therapeutic effect of THCP. Isotopes-candidates were selected for use in THCP, satisfying the following requirements:

1. the lifetime of an isotope should not exceed several days;
2. decay products must lose their energy at a distance not exceeding 1–2 mm;
3. daughter nuclei should not be toxic;
4. the mass of isotopes should be minimal when the previous conditions are met.

These conditions are satisfied by beta-active isotopes: ^{11}C, ^{13}N and ^{18}F. Statistical simulation was carried out in two stages. At the first stage, the dose distribution in biological tissues was analyzed on the basis of ionization losses in matter and taking into account their fluctuations. The dependence of the position and width of the Bragg peak as a function of the energy of nuclides in the aqueous phantom, soft tissues and tissues of the eye was determined. The second stage was used to determine the dose rate resulting from beta decay and its variation with time. Diffusion of radionuclides in tissues was not taken into account.

It was found that the dose for beta decay of nuclei is noticeably less than the dose obtained during ionization inhibition of nuclides during single irradiation. To assess the effectiveness of the effect of decay of nuclides in tumor tissues, additional biophysical studies are needed.

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MODIFICATION OF ACTIVATION METHOD OF THE ASTROPHYSICAL *S*-FACTORS MEASUREMENT

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At the methods of the *S*-factors and yields measurements of the nuclear astrophysical reactions at deep sub-barrier energies the very important factor is a ratio of the count rates of useful and background events. The passive protect is usually applied for background suppression such as underground displacement of installations (for example, например, LUNA Collaboration accelerator [1]) for reducing the cosmic irradiation, using of the no-background shielding materials and forced ventilation to protect the natural radioactivity.

We proposed and utilized before the activation method for the case when the reaction product is a short-lived radionuclide. In that the additional improvement of the “useful/background” ratio was achieved by practically momentary commutation of the target irradiation/measuring regimes and by short duration of measurement (as compared to the half-time) – when the intensity of decay is large. The statistical adequacy was attained by multiple repeating the irradiation/measuring procedure.

In [2] the two-arm scintillation spectrometer with the energy resolution of ~8–10% was used for the coincidences of the annihilation γ-quanta at formation the β^+-radioactive nuclei. Nevertheless, compelled using the rather wide energy “windows” for the signals of quanta photo-absorption leads to appreciable probability to detect the background quanta which crosses both scintillation NaI(Tl) crystals and produces two pulses within the windows width. For reducing such events we have modified the spectrometer changing the scintillation blocs by two HP Ge detectors with the energy resolution ~2 keV (for the 1332 keV γ-quanta of ^{60}Co) and the relative efficiencies of γ detection ~40%. It allows us to diminish the width of energy “windows” up to 25 times and accordingly to decrease the background level.

Test measurements of the yield of the astrophysical important proton capture reaction $^{12}C(p,\gamma)^{13}N(\beta^+)^{13}C$ by detection of the annihilation γ-quanta coincidences at the proton beam energies 300–400 keV of the EG-2 electrostatic accelerator [2] showed that, in spite of reducing of the detection efficiency relatively to the scintillation variant, the sensitivity of the method increased by the factor ~5 allowing one to measure the yields of reactions less than 10^{-15} per one projectile particle.

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NUCLEAR MICROPROBE TO BE USED AS EVALUATOR OF CATHODE ELECTRODE DEGRADATION OF CATHODE STRIP CHAMBER PROTOTYPE UNDER CMS EXPERIMENT

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The paper presents the results of investigating the structure and elemental composition of cathode electrode models of a prototype of μ-meson proportional chamber CMS after its radiation ageing on the life test installation in Petersburg Institute of Nuclear Physics. The models consisting of copper foil 36 μm thick pasted on glass fiber-reinforced plastic FR4 were taken from the zone of prototype irradiation by β-source ^{90}Sr and on unirradiated cathode areas.

Initial study of models with the use of a method of atomic-force microscopy revealed typical radiation defects: blisters, craters, flecking, pores and other phase inclusions.

The investigation of models on installation "Microprobe-EGP-10" using a method of Rutherford backscattering (RBS) demonstrated that oxygen is the major impurity in copper foil after its ageing. It was found that the amount and character of oxygen distribution in copper depended on the arrangement of the models as related to the irradiation zone.

The application of a new algorithm of RBS spectra processing using computational approaches assisted in revealing single inclusions of highly resistive copper oxide its lateral size being ~1 μm and its height being more than 2 μm. Availability of such inclusions can be considered one of reasons of spontaneous self-sustained current occurrence in proportional chambers – Malter effect.

DEVICE FOR REGISTRATION OF THE NUMBER OF PULSES AND MEASURING OF TIME INTERVALS OF RADIATION FLOWS

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When researching the characteristics of the radiation flows, the methods of sequential registration of the number of particles $K(\Delta t)$ within the defined time interval Δt are often applied.

In the experimental and industrial systems, for these purposes can be used self-contained devices capable of measuring, accumulating, promptly displaying and transmitting the obtained data by standard interfaces into the system.

For realization of these functions, a self-contained single-channel counting device has been developed, which registers the number of voltage pulses in the system's measurement channel in several operating modes.

The device allows establishing the polarity of the registered pulses, defining the interval for registration of the signal sequence, or measuring the interval of the time of accumulation of a certain number of pulses, as well as registering the time intervals between the defined number of incoming pulses. The error of duration of one exposure does not exceed 50 ns.

The parameters of the set operating modes and the current measurement results are displayed on a liquid crystal indicator.

For prompt and long-time control over the pulse flow, the device implements a function of an intensity meter with a set averaging time.

Communication with the system is realized by USB interface. The device operation control functions are performed by a programmable microcontroller.

STUDY OF THE FACTOR OF LOCAL ACCUMULATION OF DAUGHTER PRODUCTS OF RADON DECAY IN THE BODY BY THE BETA-SPECTROMETRY

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During the life of any animal vegetable or microbial organism is a continuous accumulation of isotopes and radon daughter products (DPR) their decay [1, 2]. According to the ICRP, DPR are oncoradiogenerators of tumor diseases, therefore their identification in the body can be an effective means of early diagnosis of the oncological morbidity of the population.

The purpose of this work was the fundamental research of the mechanisms of formation of nanoscale oncorodiogenic structures in the body and the development on this basis of anirac express devices for their detection.

Experiments have been performed to measure beta spectra in phantom samples of living organisms for a long time accumulating DPR. The Fig. 1 shows the spectrum of one of a series of similar measurements, from which it can be seen that indeed the accumulation effect exists and stands out well enough over the background. To implement the same measurements in the model of the express device, test measurements were carried out using CsI (Tl) photonic amplifiers.

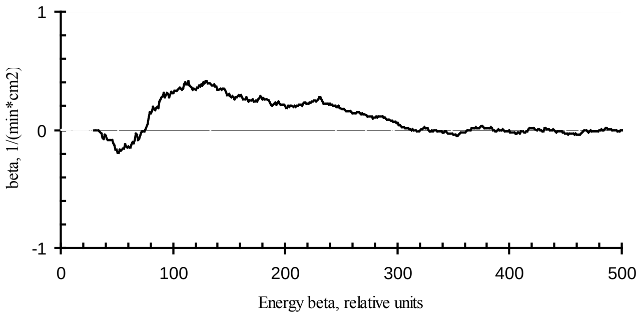

Fig. 1. The beta-radiation spectrum of the accumulated daughter products of the radon decay in the sample.

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NUCLEAR RADIATION DETECTORS BASED ON HIGH QUALITY 4H-SiC SEMICONDUCTOR

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SiC (silicon carbide) is a promising material for radiation-tolerant electronics, high-temperature electronics and high-frequency and power devices. 4H-SiC is polytype with the electron saturation drift velocity of $2{\cdot}10^7$ cm/s and the breakdown voltage of $2{\cdot}10^6$ V/cm at room temperature. This material is also a very good candidate as a material in radiation detection [1, 2]. The band gap energy of 4H-SiC is 3.26 eV and the mean energy of electron-hole pair creation is 7.78 eV. Detectors based on the 4H-SiC epitaxial layer can attain a good spectrometry of *X*-rays at room and also at elevated temperatures.

Detector structures [3] were prepared from a 70 μm thick nitrogen-doped 4H-SiC layer (donor doping $\sim 1{\cdot}10^{14}$ cm^{-3}) grown by the liquid phase epitaxy on a 3” 4H-SiC wafer (donor doping $\sim 2{\cdot}10^{18}$ cm^{-3}, thickness 350 μm). The Schottky barrier contact (Au/Ni with thicknesses 30 and 10 nm) with diameter of 2.0 mm was formed on the epitaxial layer through a contact metal mask, while full area contact from Ti/Pt/Au was evaporated on the other side (substrate).

At the IC-100 cyclotron of the Joint Institute for Nuclear Research, there is a relative quick degradation of Si detectors under impact of the high-energetic beam of heavy ions of xenon. Except this fact, there is a second effect connected with the pulse response of detector to heavy ions, which is different than that for light ions. In detail, the pulse height is lower for heavier ions. This effect is known in the literature as Pulse Height Defect (PHD) [4] and it was studied by us, too.

In our paper, we describe a new approach in which is possible to direct measure of the continual deteriorate of the parameters of detectors under Xe ions, that also included the first utilise of SiC detector for practical experiment at IC-100 cyclotron [5].

Besides this, in this paper we present the method of the observing of PHD effect at IC-100 cyclotron, when 4H-SiC and Si detectors were irradiated by the high-energetic beam of heavy ions of Xe [6].

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CHANGES OF OPERATING CHARACTERISTICS OF TRANSFORMER OIL UNDER IONIZING RADIATION

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Problems associated with the radiation resistance of electrical equipment materials that arise as a result of various emergency situations are investigated in many works devoted to determining the operability of various units and assemblies of nuclear power plants [1]. The issues became especially important after the Chernobyl Nuclear Power Plant accident in 1986. After the Chernobyl accident, a number of accidents were identified with a level greater than INES 4 (International Nuclear Events Scale) [2].

The aim of this work is to study the radiation resistance of transformer oil under the influence of γ-irradiation. It has been studied the changes in physico-chemical parameters, such as the formation of gaseous products of H_2, CH_4, C_2H_4, C_2H_6, C_3H_8, C_4H_{10}, C_5H_{12}, C_6H_{14}, density, viscosity and resistivity, depending on the absorbed doses in the range of (29.7÷237.6) kGy.

The kinetic curves of the formation of H_2, CH_4, C_2H_4, and C_2H_6 depending on the absorbed dose have been presented in Fig.1.

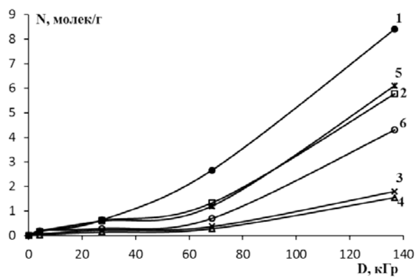

Fig.1. Kinetic curves for the formation of gaseous products of radiolysis of transformer oil, depending on the absorption dose.
1 - $H_2 \cdot 10^{18}$, 2 - $CH_4 \cdot$1017, 3 - $C_2H_4 \cdot 10^{17}$, 4 - $C_2H_6 \cdot 10^{17}$, 5 - $C_3H_7 \cdot 10^{14}$, 6 - $C_4H_8 \cdot 10^{14}$

Table. Dependence of the density (ρ) and viscosity (ν) of the transformer oil on the absorbed doses in the range of 29.7÷237.6 kGy

Dose	kGy					
	0	29.7	59.4	95	178.2	237.6
ρ, g/cm^3	0.86	0.66	0.59	0.6	0.6	0,6
ν, cm^3/s	5.42	6.52	6.24	5.69	5.96	5.73

The result shows the effective formation of gaseous products under the influence of radiation on transformer oil.

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$AgGaS_{2x}Se_{2-2x}$ SINGLE CRYSTALS FOR UNCOOLED AND PRACTICALLY NON-INERTIAL *X*-RAY RECORDING DEVICES

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$AgGaS_2$ (silver thiogallate) single crystals are promising materials for the construction of *X*-ray detectors, laser radiation converters of the intermediate IR range, and parametric quantum generators, which may find application in nonlinear optics, spectroscopy, and the communications industry [1, 2].

The aim of this study was to obtain optically homogeneous based $AgGaS_2$ single crystals with high *X*-ray sensitivity. Single crystals $AgGaS_{2x}Se_{2-2x}$ ($x = 0$; 0.5 и 1.0) were grown by using the method of chemical transport reactions (CTR).

The results of *X*-ray studies at room temperature showed that single crystals based on the $AgGaS_2$ compound crystallize in the chalcopyrite structure with the lattice parameters $a = 5.7571–5.7572$ Å and $c = 10.3110–10.3036$ Å for $AgGaS_2$ and $a = 5.992$; $c = 10.883$ Å for $AgGaSe_2$.

Single crystals of $AgGaSe_2$ grown by CTR method in comparison with $AgGaS_2$ and $AgGaS_{2x}Se_{2-2x}$ had the highest *X*-ray sensitivity. At an effective radiation hardness of 30 keV and a dose rate of $E = 10$ R/min the coefficient of roentgen sensitivity $K = 5.4 \cdot 10^{-13}$ (A·min)/(V·R) for $AgGaS_2$ and $K = 15 \cdot 10^{-13}$ (A·min)/(V·R) for $AgGaSe_2$. The coefficient of *X*-ray conductivity $AgGaSe_2$ varies within 1.2–8.5 min / R an effective radiation hardness of $V_a = 25–50$ keV and a dose rate of $E = 0.75–31.3$ R/min.

We also investigated the *X*-ray current in the $AgGaS_{2x}Se_{2-2x}$ samples and found that the dark current in the samples, in contrast to $CdIn_2S_4$ and $CdGa_2S_4$ single crystals [3, 4], reached a steady state value almost immediately after the *X*-ray radiation was turned off.

Thus the obtained single crystals can be recommended as active materials for the creation on their basis of uncooled and practically non-inertial *X*-ray recording devices.

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THE DIGITAL TDPAC SPECTROMETER FOR CONDENSED MATTER RESEARCH AT LOW TEMPERATURE AND HIGH PRESSURE

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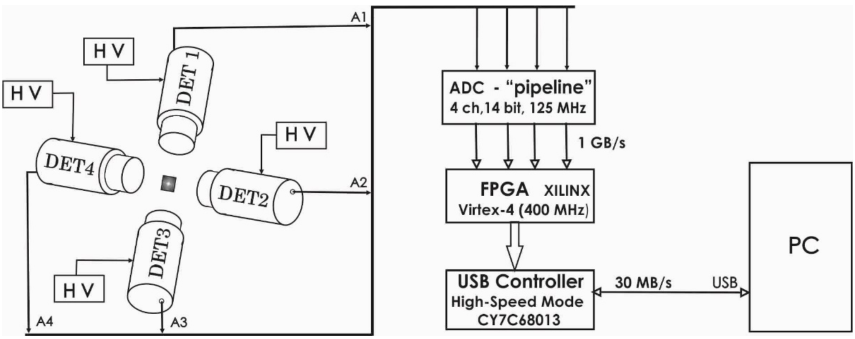
The digital time-differential perturbed angular gamma-gamma correlation (TDPAC) spectrometer was created in LNP JINR. This spectrometer is based on the four $LaBr_3$ detectors and digital signal processor. The setup is also equipped with helium cryostat JANIS SHI-950 and three high pressure cells: “toroid”-type for pressure up to 10 GPa, piston-cylinder type for pressure up to 2 GPa and diamond anvil cell (DAC) for pressure up to 60 GPa. This equipment allows us to conduct the TDPAC measurements at liquid helium temperature and at high pressure.

The new scintillation detectors and modern digital electronics and algorithms provide:

– Good energy (better than 3% at 662 keV) and time (about 400 ps for ^{60}Co cascade) resolution;
– High intensity and efficiency of recording the information (about five thousand coincidences per second);
– The compactness of the spectrometer provides mobility for conducting the measurements at different locations (on accelerators and reactors).



Block diagram of the digital TDPAC.

MODELING OF POSITRON BEAM PRODUCTION FOR USING IN NUCLEAR MEDICINE

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The possibility of obtaining a beam of positrons on a medical accelerator of electrons is investigated in this paper. The production of positron beams is an important task in physics. It is produced on special installations by two main methods: electromagnetic showers generated by electrons or photons, as well as the production of radioactive sources of positrons. Positrons are widely used in various branches of science. For example, positron annihilation spectroscopy (PAS) is a modern method of studying the structure of matter [1]. In medicine, positrons are used in positron emission tomography, which is used for diagnosis in oncology, cardiology and neurology. At present, various types of ionizing radiation are used to treat most cases of cancer. To improve the quality of irradiation, an increasingly important role is played by methods combining radiotherapy and diagnostics.

In the interaction of positrons with matter, a large number of annihilation photons are produced. The registration of such photons for coincidence can be useful in radiotherapy, in order to detect the location of annihilation and further estimate the dose. In the work, a simulation was made of the production of a positron beam based on the conversion of electrons with an energy of 20-65 MeV to electron-positron showers in various targets. The optimal thickness of tungsten and platinum targets for various energies of the initial electron beam is calculated. For electron energies of 20 MeV, the optimum thickness of the plate was 0.3 cm, and for 30 MeV, 0.4 cm. A spectrum of positrons that left the plate was obtained, and their average energy was found to be 3 to 6.8 MeV, depending on the energy of the primary electrons. The resulting positron beams can be used in intraoperative radiotherapy.

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VME BASED DATA ACQUISITION SYSTEMS

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The data acquisition systems (DAQs) should meet requirements of the modern nuclear physics experiments including investigations with radioactive ion beams. We want to show on two examples how this can be implemented in DAQs based on VME standard. First example is the DAQ [1] developed together with GSI experts for the new in-flight fragment separator ACCULINNA-2 [2], which have possibility to work with several crates in VME, CAMAC and other standards. The main advantage of this system is that it allows the remote DAQ (event collector) to be located at the distances up to 100 meters far from the main event builder. The mode of operation of this DAQ is configurable depending on running experiments. As second example, VME based DAQ with USB controller [3] will be reported as well. It is effective for applied physics and for experiments with limited numerical parameters (several hundreds).

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ACCELERATOR COMPLEX FOR FUNDAMENTAL RESEARCHES BASED ON ELECTRON LINAC ЛУЭ-8-5 РВ

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Arised up lately interest in the investigations of photonuclear reactions near threshold (at energies of electrons and photons below 10 MeV) demands the electron beams with the improved properties compare with industrial samples.

In this report the results of works allowing to get on electron linac ЛУЭ-8-5 РВ [1] the beam of electrons with shown below parameters are described. The beam energy may be established within the limits of 4–10 MeV, width of spectra – from 1% (FWHM) at current up to 6 μA and 10% at the maximal current to 300 μA at repetition rate 300 s^{-1} and pulse width 3 μs.

The high resolution beam is got with the use of the special magnetic system with beam deflection on 270 degrees [2].

Within last year several experiments on excitation of nuclei-isomers in pigmy resonance region and on measuring of electron – to positron conversion for the number of nuclei near a threshold were fulfilled.

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SIMULATION OF PRECISE EXPERIMENT OF LOSS COEFFICIENT MEASUREMENT DEPENDING ON VELOCITIES OF UCN WITH GRAVITATIONAL SPECTROSCOPY

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Very low energy neutrons ($\approx 10^{-7}$ eV) called ultracold neutrons have a unique property – they can be stored in material or magnetic traps [1]. This gives a new opportunity to carry out experiments to study fundamental physics issues.

Most of UCN experiments are statistically limited. And we are today at a point at which fundemantal physics application require larger UCN intensities in order to further advance. But nowadays the intensities of UCN that we have are not enough and require further advance. Thus, most of researches centres are working on increasing of existing UCN sources or on building new intense sources of UCN to develop experiments of neutron measurement and to improve their accuracy. Various developments have allowed one to increase the intensity of UCN considerably over the years. One of them is work, which was provided by FLNP JINR physicists [2]. One of the important parts of this work is storage vessel of UCN, which has to store maximum number of UCN. Consequently, one should note that task of building a UCN production trap from a technologically convenient material with minimum loss coefficient and high optical potential.

This work is devoted to simulation of precise experiment of loss coefficient measurement depending on velocities of UCN with gravitational spectroscopy and to choose optimal parameters of storage volume. The effect of various covers and materials of trap on loss coefficients preliminary was estimated.

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EVALUATION OF NONHOMOGENEITY OF LARGE SEQUENCES OF EMPIRICAL DISTRIBUTION SERIES OF RADIATION FLOW PARTICLE COUNTS BY SMALL SAMPLES

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In the problems of the analysis of empirical distribution series - (ES($K(\Delta t)$)) of counts $K(\Delta t)$ over time intervals Δt of flows of any radiations with the mean $\overline{K}(\cdot) = \nu\Delta t$ and intensity ν, it is necessary to identify ES(·) and evaluate their conformity, including a parametric one, with some model. If the sequence of M such ES(·) is obtained over samples $(K_1,\ldots,K_n)$ of small volume n < 100, then the decision about their homogeneity and conformity with the model does not usually have enough reason, i.e. criterion. In the sequences of M>>1 random vectors $(n_0,\ldots,n_l)_{S,j}$, i.e. various types of $\text{ES}(\cdot)_{S,j}$ with ordinal numbers $1 \le S \le M$, where $n = \sum_{i=0}^{l} n_{ij}$, $n_{ij} = n_{ij}(K(\cdot) = i)$ – the number of equal values of K_i in the sample of volume n, identical $\text{ES}(\cdot)_j$ are formed with random frequency M_j. The average value of M_j is $\overline{M}_j = MP_j$, where P_j – polynomial probability of formation of one $\text{ES}(\cdot)_j$, and the dispersion $D(M_j) = MP_j(1 - P_j)$, since M_j corresponds to the binomial, and at $1 \ll M$ and $P_j \ll 1$, also to the Poisson distribution. Distribution of intervals r_j between M_j identical sequences of $\text{ES}(\cdot)_j$ conforms with the geometric and exponential ones for $r_j \gg 1$.

At $n < 100$ and $\overline{K} < 10$, within the limits of the statistical spread of values of M_j and r_j, i.e. within their confidence intervals Δ_j can fall more than one value of M_j, and r_j for various types of ES(·). The power form of dependence of random value $L(\cdot)$ – the number of various types of $\text{ES}(\cdot)_j$ with equal M_j and r_j linear in logarithmic scale $\log L(M_j) = a - b \log M_j$, $\log L(r_j) = c + d \log r_j$ is attributable to the growth of the relative confidence interval for P_j in the form $\delta_j \sim M_j^{-1/2}$ and growth of density of various ES(·) in confidence interval Δ_j.

Distribution of rounded off to the integer values of MP_j, to which correspond equal binomial M_j forming $L(M_j)$ is a generalized binomial distribution, which at $M_j \gg 1$ $L \to 1$ becomes symmetric. Random value L, which is the sum of a random number of random ES(·), also conforms with the generalized binomial distribution. By dependences $\log(M_j)$ and $\log(r_j)$ we can also evaluate P_j, M_j and types of $\text{ES}(\cdot)_j$, at which L=1, $L \ll 1$ as well as evaluate the homogeneity of sequences of ES(·).

FEATURES OF ELECTROMAGNETIC FIELD GENERATED BY INTERACTION OF HIGH ENERGY ELECTRONS WITH SOLID MEDIUM TAKING INTO ACCOUNT SECONDARY PROCESSES

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As part of the quasi-classical approach to describe the characteristics of the electromagnetic fields of the electrons produced by the interaction of ionizing radiation with the environment [1], the changes of the electromagnetic field components at different angles of observation in the space time representation are calculated.

In the model experiment, describing the interaction of electrons with energy of 1.9 MeV with mica, the distribution of electrons in the phase space in a substance in the solid state is obtained using GEANT4 package [2]. The calculation of electromagnetic fields formed by electrons passing through matter is performed.

We applied the technique previously used for calculation of fields produced by ionizing particles in gas and liquid medium [3, 4]. The principle of superposition and model of linear current were used.

It is shown that the calculated angular distribution of energy changes is in a good correspondence with the experiment [5].

This work was performed using equipment at the St. Petersbug State University Computer Resource Center.

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SIMULATION OF ENERGY DEPOSITION IN PATIENT BODY DURING EXPOSURE FROM *X*-RAY CT

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We performed a computer simulation of energy deposition in body of patients exposed to *X*-ray computed tomography (CT). The objective was to estimate the radiation doses to organs and tissues. We developed a model of a dynamic source using Monte-Carlo method. Both axial and helical modes of CT operation can be simulated. The dependence of dose on volume of scanning, distance to source, center of the body position and characteristics of the beam are taken into account.

Human body was simulated using voxel phantoms [1]. The phantom was vertically cropped to the direct radiation field and adjacent slices.

Absorbed radiation doses were calculated in head of an adult human with various settings of radiation field. An example of dose distribution is shown in Fig. 1 (4.3 cm from top of head of an adult, 100 kV, medium M bowtie filter).

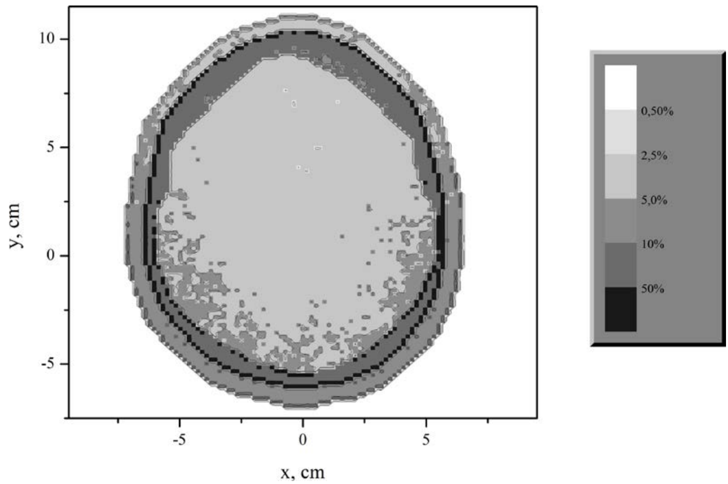

Fig. 1. Relative dose distribution in transverse plane of head of an adult female during exposure to X-ray computed tomography.

The results of the study show that the maximum dose is absorbed in bone. Dose in skin is higher than during conventional *X*-ray radiography.

The research was performed with a financial aid of Belarusian Republican Foundation of Fundamental Research (grant F16M-037).

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FEATURES OF THE INFLUENCE OF IRRADIATION ON STRUCTURE OF STRUVITE-K

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A complex comparative study of the characteristics of the initial and irradiated Struvite-K [$KMgPO_4 \cdot 6H_2O$] samples (~10 μm) was performed using *X*-ray diffraction analysis, IR-spectrometry, activation analysis, crystal-optical analysis using immersion preparations [1, 2]. A study was also made of the selectivity of radionuclide sorption, cesium capacity, kinetic characteristics of the fine-dispersed magnesium-potassium-phosphate nanoceramics $KMgPO_4 \cdot 6H_2O$ during the ion exchange using the ^{132}Cs isotope obtained in the $^{133}Cs(\gamma,n)^{132}Cs$ reaction.

It is shown that after irradiation with bremsstrahlung to a dose of 1.35 10^5 Gy and electrons at doses of 1 and 100 MGy, the phase composition of the images does not change significantly. Crystallization of amorphous phosphate and structural ordering of Struvite-K and magnesite occur. The diffusion coefficients Cs, Sr, Na, etc. were calculated from leaching data from the initial and irradiated samples. A forecast is made in the sustainability and the possibility of further use of Struvite-K after radiation exposure.

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PRODUCTION OF OSTEOTROPIC ISOTOPES BY PHOTONUCLEAR METHOD

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Experimentally, rare-earth β^--emitters of ^{153m}Sm and ^{175}Yb have been obtained, which have recently been widely used in radionuclide therapy of metastatic bone lesions in various malignant tumors [1, 2]. The urgency of radionuclide therapy for the treatment of bone metastases is due to the ability of β–radiating isotopes to selectively accumulate in pathological foci.

The Sm_2O_3 and Yb_2O_3 nanoparticles were used to obtain ^{153m}Sm and ^{175}Yb with high specific activity by means of recoil nuclei from the reactions ^{154}Sm(γ,n)^{153}Sm and ^{176}Yb(γ,n)^{175}Yb, respectively, in clinoptilolite, which in this case acts as an acceptor. Activation of the samples was carried out on a linear electron accelerator with E = 13 MeV. The isotope activity in the acceptor was measured by a Ge(Li)-detector. The proportion of recoil atoms of ^{153m}Sm in clinoptilolite was ~12.3%, and ^{175}Yb ~1.7%. The presence of impurity isotopes was not observed in the samples.

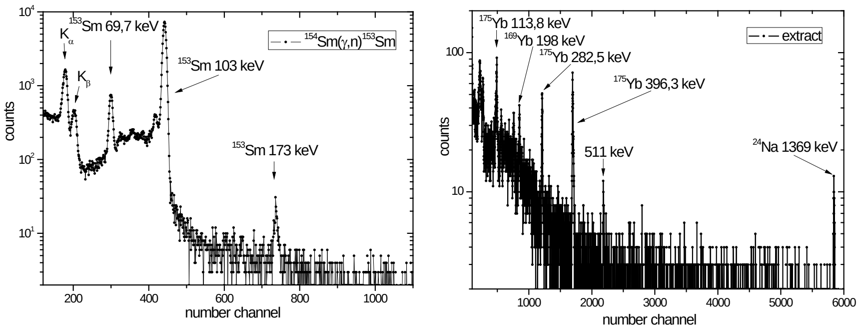

Fig. 1. The spectrum of Sm after irradiation by bremsstrahlung with E_{max} = 12.5 MeV (left), the spectrum of separated clinoptilolite particles with recoil nuclei ^{175}Yb irradiated by bremsstrahlung with E_{max}=13.5 MeV(right).

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MONITORING OF NEUTRONS FIELD OF THE REACTOR VVR-SM AT RECEPTION OF PHOSPHORUS-33

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Cobalt metal disks (∅ = 3.0 mm) from cobalt aluminum alloy with 0.01% content of cobalt-59 [1] and samples of sulfur-33 (m = 1.0 mg) packed in quartz capillaries (∅ = 2.0 mm, L=10÷15 mm) were used for monitoring neutrons field of reactor VVR-SM at reception of phosphorus-33 by nuclear reaction $^{33}S(n,p)^{33}P$.

Cobalt-59 and sulfur-33 support monitors packed together with the initial material (sulfur-33) and was irradiated by thermal neutrons in the vertical channel of the reactor.

Sulfur-33 monitor after irradiation was dissolved in small volume of organic solvent (hexane), than practical activity of phosphorus-33 radionuclide was determined by measuring activity of aliquot parts of phosphorus-33 solution.

Beta-gamma-spectrometer «Progress BG (II)» BDEB 3-2U with the software "Progress 5" was used for measuring cobalt-59 and sulfur-33 monitors' activity.

Monitoring results of thermal neutrons stream density and received practical activity of radionuclide of phosphorus-33 is shown in the Table 1.

Table 1. Monitoring results of neutrons field of the reactor VVR-SM and received practical activity of radionuclide of phosphorus-33

№	Weight of S-33, g	Duration of irradiation, hour	Number of vertical channel	Thermal neutrons stream density, n/sm^2·s	Calculated activity of P-33, mCu/g	Practical activity of P-33, mCu/g
1.	4.0	1391.0	3-2	$0.47\cdot10^{14}$	229	214
2.	4.4	1391.0	2-6	$0.45\cdot10^{14}$	220	210
3.	5.0	623	4-2	$0.7\cdot10^{14}$	129	121
4.	5.0	321	3-3	$0.8\cdot10^{14}$	152	140

Experiments identified that for reception of phosphorus-33 with high specific activity (120–140 mCu/g) irradiation of sulfur-33 in vertical channels of the reactor VVR-SM following mode is needed: thermal neutrons stream density is $\geq 0.7\cdot10^{14}$ n/sm^2·s and irradiation duration is 320÷620 hours.

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DEVELOPMENT OF THE STATIONARY RADIONUCLIDE GENERATOR OF ^{188}W-^{188}Re

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The enriched tungsten trioxide was irradiated by neutrons of the reactor VVR-SM during 2290 hours at the neutrons stream density of $0.6 \cdot 10^{13}$ n/sm^{2}·s. From the irradiated tungsten trioxide with concentration of W=6.0 g was prepared izopolivolframat solution sour (pH=3.0) with concentration of W=24 mg/ml. Then the izopolivolframat solution with parent radionuclide of ^{188}W was passed through stationary generator column [1] with specially prepared of chromatography aluminum oxide (*m*=100.0 g) [2]. Stationary generator has been supplied with glass filter and communication system for input and output of elute. Generator column height is 250 mm and diameter is 2.5 mm.

Investigation results have shown that 33.0 % of aluminum oxide layer of stationary generating column is free volume column and does not contain parent radionuclide of ^{188}W (Fig. 1.). Generator column with 66.7 % aluminum oxide have been loaded by tungsten with average concentration of W=90 mg/g. The maximum concentration of W=171 mg/g whereas concentration of W=3.2 mg/g.

From stationary generator of ^{188}W-^{188}Re solution of sodium perrenatum (Na^{188}ReO$_4$) was eluted by 0.9 % isotonic solution eluent, with additive of nitrate ions. Curve of elation of Na ^{188}ReO$_4$ solution is shown in Fig. 2.

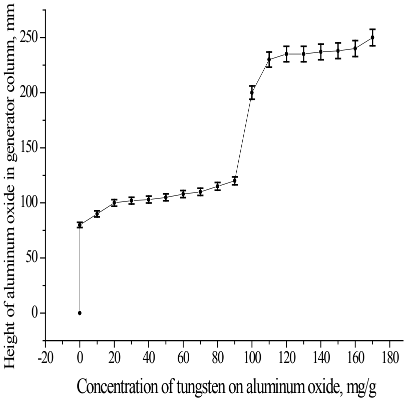

Fig.1. Curve of distribution of tungsten on aluminum oxide of the stationary generator.

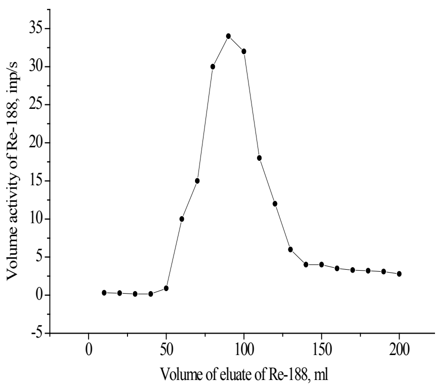

Fig.2.Curve of elation of Na^{188}ReO$_4$ solution from stationary generator.

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THE CHARACTERISTICS OF CARBON DETECTION WITH USING OF $^{13}C(\gamma,p)^{12}B$ ACTIVATION

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The method for carbon detection was proposed in [1, 2] with registration of produced ^{12}B activity (the life time $T_{1/2} \cong 20.2$ ms) in the $^{13}C(\gamma,p)^{12}B$ reaction [3]. Emission of γ-quanta at decay of ^{12}B produced in the several specific targets was calculated in [4]. For the attempt to realize this method [1] there was given in [5] the model description based on MCNPX-5 [6]. Because of complexity of the task in the present work we checked the results from [5] by the independent estimations of the main method characteristics.

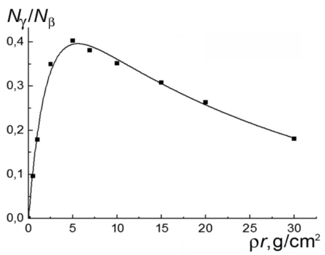

Fig. 1. Total (N_γ/N_β) for emitted γ-quanta at ^{12}B-decay in dependence on target thicknesses ρr.

The calculations in [5] and in this work (according to [7]) of ^{12}B-nuclei quantity produced per an incident 50 MeV electron in the graphite target (5 cm×∅6 cm) both gave about $1.4 \cdot 10^{-6}$. The total flux densities at an End Of Bombardment for γ-quanta caused by ^{12}B-decay in the target from the model [5] and from this work are respectively $\nu_\gamma \approx (0.8$ and $0.5) \cdot 10^{-12}$ cm^{-2}·ms^{-1}. The estimation of ν_γ in this work was made using data per a decay β-particle from [4] and from the present work. There were used spectra in energy E_γ for emitted γ-quanta $(\Delta N_\gamma/\Delta E_\gamma)/N_\beta$ and integrated fluxes of emitted γ-quanta (N_γ/N_β) in dependence on target thicknesses ρ*r* for a set of minimal energies $E_{\gamma\,\min}$. (see Fig. 1. for $E_{\gamma\,\min} = 0$). It is interesting to note that the shape of (N_γ/N_β)-dependence on target thicknesses is similar to that from [8] for incident on targets electrons with energy ≈17 MeV.

The present results confirm the model description [5] and can be useful at optimization of the considered method for carbon detection.

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TIME OPERATIONAL MODE OF SCINTILLATION DETECTORS FOR MEASURING INDUCED ^{12}B- AND ^{12}N-ACTIVITIES AT PULSED ELECTRON ACCELERATORS

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For the purposes as fundamental (development of modern models for nuclear reactions, see, e.g., [1]) as applied (development of the photonuclear method for detecting hidden explosives, see, e.g., [2]) it is necessary to measure with scintillation detectors induced activities of short-lived radioisotopes ^{12}B (life-time $T_{1/2} \cong 20.2$ ms) and ^{12}N ($T_{1/2} \cong 11.0$ ms) produced respectively in the reactions ^{14}N(γ,2p) and ^{14}N(γ,2n) at pulsed electron accelerators. Because of such a low level of $T_{1/2}$-values this sort of measurements should be producing directly in accelerator halls in rather short time intervals after each accelerator beam pulse and at an appropriate beam repetition rate. But in these measurements it is necessary to solve the following task: to avoid (or at least to decrease to a large extent) negative influence on used scintillation detectors from background of γ-quanta and neutrons, produced by an accelerator beam pulse, and from a usually serious electromagnetic noise from mighty high-frequency devices of a pulsed electron accelerator. It is useful to compare this task with that which takes place in measuring production of delayed neutrons from fissionable nuclei at pulsed electron accelerators (see, e.g., [3]).

For solving this task we choused the known way with power supply changing for dividers of photomultiplier tubes (PMT) for used scintillation detectors before and after each beam pulse (see, e.g., [4, 5]). It is important to point out advantages to use for these purposes positive power supplies of PMT. Taking into account possibility for production of secondary electrons under *X*-rays on PMT dynodes (what was noted in particular in [6]) we decided to use for such changing several dynodes after photocathode in PMT. Efficiencies of choused operational modes for scintillation detectors were tested with light-emission diodes, with radioactive sources and with beams of pulsed linear electron accelerator LUE-8-5 in our laboratory of photonuclear reactions in INR RAS.

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ON THE MEASUREMENT OF THE DECAY ENERGY OF THORIUM-229 ISOMER

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Decay of the low-lying state of thorium-229 with emission of electrons of internal conversion was observed in [1]. In the same paper, the upper and lower limits for the energy value of the isomeric state have been set. The ambiguity of the interpretation of the spectrum of the electron conversion from atoms planted on the surface, as suggested in [2, 3] apparently will not allow to determine the exact value of the transition energy. To determine the electron energy from the decay of the ^{229m}Th, it is proposed to use a combination of a radio-frequency multipole ion trap and an electron spectrometer with magnetic collimation.

The method of formation of the ^{229}Th ion beam is described in [2, 4]. It is proposed by us to inject mass-separated ions into the multipole rf-trap, where they are neutralized in the charge-exchange reaction with neutral barium atoms added to the helium flow. The conversion electron is emitted within a few microseconds after neutralization. To determine the energy of conversion electrons in the range of 0–20 eV, it is planned to use a MAC-E spectrometer connected with the ion trap like offered in [5].

The design and simulation results of the spectrometer are discussed. The optimal conditions for capturing and retaining ions in a trap, the distribution of ions and neutral atoms of thorium and the conversion electron spectrum obtained at the same time are evaluated. The simulation allows to estimate the expected resolution of the spectrometer as ~ 0.1 eV. Effects associated with formation of metastable states, and with the molecular compounds of thorium ions and with the background conditions are discussed. It is of great interest that the lifetime of fresh Th isomers may essentially depend on the ambient conditions through collisional broadening [6], which may take place in the mass separator and rf trap. One should take this into account, as efficacy of the setup as a whole depends on this circumstance.

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DETECTION OF DELAYED NEUTRONS NEAR THE THRESHOLD OF URANIUM PHOTOFISSION

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The investigation of yield and energy distributions of delayed neutrons (DN) in photofission provides us with the information useful for understanding of fundamental properties of the process, as well as for practical applications, in particular, for detecting of fissile nuclear materials in cargo containers [1]. In this case the data acquired near the photofission threshold when the γ-quanta energy is rather low for activation of the container walls and other construction materials present a great interest.

The measurements were carried out on the bremsstrahlung γ-quanta beam emitted by a linear electron accelerator LAE-8-5 INR RAS with the energy of 8 MeV. A sheet of tungsten with the thickness of 400 μm was used as a bremsstrahlung emission radiator; the accelerator repetition rate was 50 Hz. The irradiation of natural uranium target was conducted with the average current of ~0.1 μA and electron energy of ~7 MeV. A stilbene-based scintillation detector was used for measurement of neutron spectra. The detector was placed at a 135° angle towards the beam and at a distance of ~15 cm from the uranium target. For shielding against background radiation Pb protection with a thickness of ~60 mm was used all over detector. For γ-quanta background suppression, a method of scintillation pulse shape discrimination was used [2]. Suppression of pulse pile-up effect in the detector was carried out by increasing the number of integration intervals to three [1] with a duration of 400 ns for each. The start of integration of the full charge was set to 30 nanoseconds before the start of the scintillation pulse. The start of integration of two “slow” components was set at 20 ns and 40 ns after the pulse front. The ratios between the 3 values were used both for the particle discrimination and for the overlap suppression in “off-line” mode. Since while conducting the experiment we didn’t turn off the photomultiplier at the moment of γ-quanta beam passing, we chose for registration a time interval of 4–20 ms after each accelerator impulse. As a result, the DN yield with electron energy of ~7 MeV and beam current of ~0.1 μA averaged ~10 neutrons/sec.

This work was supported by the RSF, grant №16-12-10039.

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INVESTIGATION OF THE GAMMA QUANTA AND NEUTRONS FLUXES DURING THE MEDICAL ELECTRON ACCELERATOR OPERATION

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During radiotherapy using bremsstrahlung gamma quanta with energies greater than 8 MeV, nuclear reactions with neutron emission take place on the brake target and structural materials of a linear accelerator. Because of the high radiobiological danger of neutron radiation, especially fast neutrons, their contribution to the total beam flux substantially increases the dose received by the patient.

We conducted studies of the braking gamma quanta and neutrons flows directly at the place of the patient's treatment at a distance of 1 m from the virtual source of gamma quanta with a radiation field size of 20×20 cm^2. The use of direct spectrometric methods for measuring the flux of gamma quanta and neutrons in this case is extremely difficult due to the high flux density (according to some estimates $\sim10^{12}\cdot$particles$\cdot$cm^{-2} s). Therefore, for solving this problem, we used the photoactivation method. Registration of gamma quanta and neutrons was carried out using (γ,n) and (n,γ)-reactions. The natural tantalum ^{181}Ta as one of the most studied nuclei in both photonuclear reactions and in reactions with neutrons in a wide energy range, was used as a detecting target. For the experiment, two Varian Trilogy medical accelerators with different operating life were used: *accelerator 1* with long operating life (boundary energy 18 MeV); *accelerator 2* with short operating life (boundary energy 20 MeV).

Irradiated targets were measured with a large-volume semiconductor Ge-spectrometer with an energy resolution of 1.5 keV on a 661 keV ^{137}Cs gamma line. The gamma quanta of ^{180}Ta with the half-life $T_{1/2}$ = 8.15 hours formed in the (γ,n)-reactions and ^{182}Ta with the half-life $T_{1/2}$ = 115 days formed in the (n,γ) reaction were reliably identified in the measured spectra. The ^{180}Ta activity was 220 Bq for the irradiated target at an energy of 18 MeV and 1540 Bq for the irradiated target at an energy of 20 MeV. The ^{182}Ta activity was 2.6 Bq and 34 Bq for the targets irradiated at 18 MeV and 20 MeV, correspondingly. Using the calculated integral cross sections, it was found that the neutron flux was 16% of the gamma-ray flux during the accelerator 1 operated and 5% during accelerator 2 operated.

Also, irradiation of aqueous phantoms at different distances from a direct beam of gamma flux was performed to estimate the dose from neutrons. On the phantoms were placed 3 thermoluminescent dosimeters DVGN-01. The data obtained from measurements using thermoluminescent dosimeters are in good agreement with the results obtained by the photoactivation method.

PHOTOACTIVATION TECHNIQUE FOR DETERMINING OF ^{10}Be ACTIVITY IN REACTOR STRUCTURAL MATERIALS

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One of the important and dangerous radionuclides formed in reactor structural materials is ^{10}Be. It has a half-life $T_{1/2} = 1.6 \cdot 10^6$ years and decays with the only electrons emission with a boundary energy of 536 keV. For measurement of reactor structural materials activities, it is necessary to select ^{10}Be with radiochemical methods, but this is a complex and expensive task. The solution of this problem can be found using the photoactivation technique to determine the concentration of ^{9}Be in the samples with the subsequent calculation of ^{10}Be activity. In the reaction (γ,2n) on ^{9}Be, ^{7}Be is formed with $T_{1/2}$ = 53 days. In the reactions (γ,np), (γ,n), various gamma nuclides are also formed on the samples main elements. Their measurements as well as ^{7}Be measurement, are carried out on gamma spectrometers. In particular, Be determination from structural materials relates to the isotopes Fe, Co, Ni in some researches.

To determine of the Be contribution to reactor structural materials, samples with a 50 mg mass were irradiated with a bremsstrahlung γ-quanta flux with a boundary energy of 37 MeV. Irradiation was carried out for 3.5 hours with an average electron current of 5 μA. The measurements were carried out after a month hold using a semiconductor Ge-spectrometer with an energy resolution of 1.5 keV on the ^{60}Co line. As a result, it was found that the contribution of ^{9}Be is $5 \cdot 10^{-4}$ of the total sample mass. Using the obtained data, the ^{10}Be activity in the sample with a maximum yield of ^{7}Be was calculated as 0.09 Bq/g. To control this method results, we irradiated samples with a 50 mg mass using a bremsstrahlung γ-quanta stream with a boundary energy of 55 MeV. Irradiation was carried out for 1.3 hours with an average electron current of 40–45 nA. The measurements were carried out a day and a month after exposure. The results are discussed.

DEVELOPMENT OF STRIP AND PIXEL DETECTORS BASED ON CdZnTe

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We used CdZnTe crystals from Redlen Technologies with the size 10×10×5 mm^3 to create detectors. Pixel structures of 6×6×5 mm^3 and 4×4×3 mm^3 were manufactured. A detector 6×6×5 mm^3 has a pitch 1100 µm, a pixel count of 16 and a square pixel size 1000 µm^2. Two types of stripe detection structures were made, all structures had a pitch 500 µm, a number of strips – 16, a strip width is 400 µm. Structures also have guard rings.

The results of a study of the spectrometrical characteristics of the detector single crystals CdZnTe obtained from materials of Redlen Technologies are presented in table.

Sample number	Type of detector	Instrumental resolution (keV) at energy:			
		81 keV	122 keV	356 keV	662 keV
1	pixel 4×4×3 mm^3	5.8	13.5	–	32.5
2	pixel 4×4×3 mm^3	4.6	6.1	9.2	–
3	pixel 4×4×3 mm^3	–	7.1	–	31.5
4	pixel 6×6×5 mm^3	4.6	5.5	12.2	30.8
5	pixel 6×6×5 mm^3	4.8	10.0	18.2	59
6	strip 10×10×5 mm^3	5.4	7.1	–	24.5
7	strip 10×10×5 mm^3	4.7	6.8	9.2	13.8
8	strip 10×10×5 mm^3	–	6.9	–	21.1
9	strip 10×10×5 mm^3	–	6.7	–	30.9

The results of these investigations are of interest for monitoring nuclear materials using compact devices with high energy resolution that do not require cooling.

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A NEW DETECTOR FOR STUDYING CUMULATIVE PROCESSES IN HADRONIC COLLISIONS

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The increase of the luminosity at Super Proton Synchrotron (SPS) at CERN, planned after 2020, makes possible to expand the field of research in experiments on a fixed target. In particular, more detailed study of the so-called cumulative processes [1, 2] can be carried out. These processes could be identified by detecting of secondary particles and nuclear fragments in the kinematic region forbidden for the nuclear-nuclear reaction.

The correlations of cumulative particles with the particles at forward hemisphere (in particular with D0 mesons) should provide the insight of a new mechanism of heavy flavor production in the reactions with heavy ions [3, 4]. For the particle tracking and precise secondary vertexes identification at low momenta the Monolithic Active Pixel Detectors based on CMOS technologies has been proposed. In order to register particles with high momenta (up to 4 GeV/c), the possibility of using Cherenkov detectors is considered.

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FUNDAMENTAL PROBLEMS OF NUCLEAR POWER AND NUCLEAR TECHNOLOGIES

EXPERIENCE AND PROBLEMS OF QUALITATIVE TRAINING OF RUSSIAN AND FOREIGN SPECIALISTS IN FIELD OF NUCLEAR PHYSICS, ATOMIC POWER ENGINEERING AND NUCLEAR TECHNOLOGIES

S^3-DETECTOR OF THE REACTOR NEUTRINO (STATUS OF THE PROJECT)

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S^3 project is devoted to the creation of a relatively compact spectrometer which does not contain flammable or other dangerous liquids and can therefore be located in a close proximity to the industrial power reactor. One of the main tasks of the spectrometer is the remote monitoring of the reactor routine operation thus providing an independent method for the thermal power measurement of the reactor and the change of the fuel composition determination – the amount of uranium burned out and plutonium produced.

The S^3 detector is composed of segmented plastic scintillator with a total volume of 64 dm^3, surrounded by the passive and active shielding against the external and internal radiation background. The basic element of the detector is a plate ($20\times40\times1cm^3$) made of polystyrene-based scintillator with scintillating and wavelength shifting dopants of PTP and POPOP. The light signal is transferred from the plate to the PMT via of a spectroscopic optical fibers is expected to provide about 70–80 p.e./Mev.

Different tests were performed in order to optimize the chemical composition of the plates, signal processing and electronic and optical components to be used (PMT, fibers etc.). Detector construction in the laboratory is already in progress. It is expected that at the distance of 11 meters from the reactor core S^3 would detect 300-400 IBD per day.

ACTINIDES ^{237}Np, ^{241}Am, ^{239}Pu IN THE NEUTRON FIELD OF «QUINTA» SETUP

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The experiments were carried out within the framework of the project "Energy and Transmutation of RAW" and aimed at solving the problem of the transmutation of actinides – neptunium, americium, and plutonium. These elements, among the other fifteen actinides, are artificially formed in the reactor, as a by-product, that actively absorbs neutrons.

The aim of this paper is to compare the cross sections for the capture and fission reactions at different radii of the «Quinta» setup and to determine their ratio [1] for the residual nuclei in the ^{237}Np (Fig. 1), ^{241}Am and ^{239}Pu targets in the neutron field [2, 3] at different radii (R_{max} ~150 mm) of the uranium (^{238}U) assembly «Quinta» irradiated by protons with the energy of 660 MeV, 2 GeV/d, 4 GeV/d, 8 GeV/d.

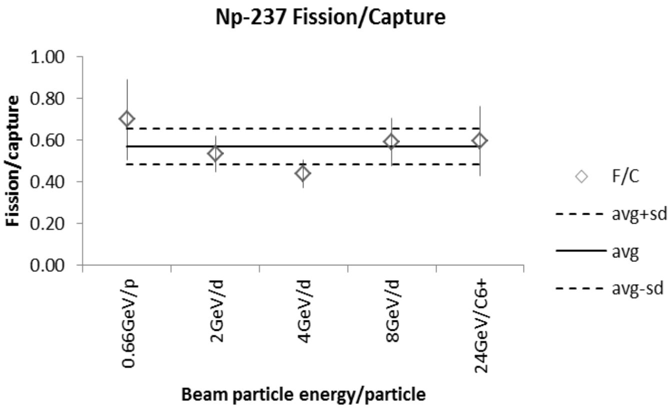

Fig. 1. Np-237 fission to capture ratio for each experiment [1].

There are two channels for the interaction of actinides with neutrons - fission and capture [1].

The activity of the formed products is determined by registration of the gamma radiation by germanium detectors [3].

In the report, the experimental results are compared with the calculations for different neutron energies.

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A STUDY ON THE TRANSPORTATION OF REACTOR PRODUCED EXOTIC NUCLEI BY THE GAS-JET METHOD

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For the purposes of precise mass measurements of beta-unstable short-lived exotic nuclei at the future planned facility PITRAP [1] on the PIK-ractor in Gatchina (Russian Federation), a study has been done on the gas-jet transportation method, which is used for fast transportation of fission products from the reactor's active zone to the measuring setup. The study consisted of three main parts: experimental study of the gas-jet transport method, theoretical modeling and optimization of the experimental results and evaluative predictions in the case of the PIK-reactor.

From the experimental data obtained on the TRIGA-reactor in Mainz (Germany) the fission products transport time has been evaluated ranging from 941 ms to 1505 ms using volumetric flows of nitrogen in the interval from 400 mL/min to 800 mL/min [2]. From the experimental gamma spectra obtained at the end of the capillary system at the TRIGA-SPEC facility, around 27 high-yield beta-unstable nuclei have been successfully identified, which have survived the transport process and the experimental conditions.

As a result of the mathematical modeling of the cumulative transportation experiments a formula for the transport time has been derived, which approximately describes the experimentally obtained results. Also from the identification experiments of transported fission products a formula for the critical curve has been derived, which expresses the criteria for the survival of nuclides during the transportation process, which is dependent from the combinations of the nuclear half-life $T_{1/2}$ and cumulative fission yield Y_c.

An additional study was made on the optimization of the gas-jet process, in which a possible use of different carrier gas has been examined, which included all the noble gasses. As a result of the optimization study it was concluded that in the case of using He as a carrier gas, the lowest possible restrictions on the experimental conditions are imposed and at the same time the shortest transport times can be obtained.

Evaluative predictions have been made of the possible surviving short-lived nuclei in the case of the planned experimental conditions on the PIK-reactor, which yielded with a number of yet unstudied nuclei, which are impossible to be observed under the experimental conditions present at the TRIGA-Mainz facilities.

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A QUASI-INFINITE TARGET ^{238}U ON PROTON BEAM

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The problem of efficient utilization of the worked-off nuclear fuel (WNF) has become a basic topic in the discussion of future global energetic last years. Developed countries start to discuss seriously the utilization of electro-nuclear systems (in international terminology: Accelerator Driven Systems – ADS) as an alternative and perspective method of resolution of this problem. A quite energy stiffness of the neutron spectra in the comparison with the divisanable one, that would permit instead of the traditional for the nuclear reactors reactions (n, *f*), and (n,γ) to use efficiently a complex of multistep cascade reactions, a high energetic proton, mezon and neutron division, and also a threshold reactions of the type (n,*x*n) associated with the producing of neutrons has been supposed in the project. A neutron spectrum of this type would permit “to burn” efficiently threshold minors of Actinides and transmute the long-living pieces of nuclear division into the WNF downloading in the active zone (AZ) [1, 2].

The project “Energy and Transmutation of Radioactive Waste” is aimed to decide several basic tasks such as follows: a) a development and analyzing of methods and systems of the measurements, concerning the nuclear physics processes’ characteristics, ensuing in the extended Uranium target under the influence of the relativistic particles’ beam, b) a limited modeling of the central area in the target set-up that is a kind of a realistic prototype of the quasi-infinite AZ in nuclear fuel decay scheme and c) Fundamental and applied researches associated with the interactions of the relativistic particles with massive multiple targets having the only aim to test and to modify the existed models and transported codes. Basic scientific and methodological results of the project are discussed in the report (Fig. 1).

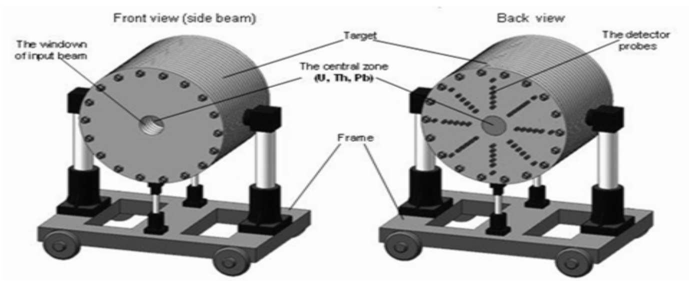

Fig. 1. A common view of the target set up of ^{238}U, established on the transport and adjusted platform in the centre of the proton beam 660 MeV, in the Phasotron LNP, JINR.

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ESTIMATION OF FUEL ASSEMBLES MODIFICATION POSSIBILITY FOR NUCLEAR REACTORS ON THERMAL NEUTRONS

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Different nuclear fuel cycles are investigated. Total amount of cycles are estimated for different fuel enrichment and specified quantity of delayed neutrons. β_{eff} dependence of initial enrichment and fuel campaign duration is studied. Computer program for these processes is developed. Numerical computations are carried out.

REMIX FUEL RADIOACTIVITY INFLUENCE ON FUEL CYCLES REDUCTION

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Computer program for some neutron-physical characteristics of modern thermal neutron reactors is developed. Minimal percent of nuclear fuel enrichment is estimated for WWER-1200 reactors. Total amount of produced Pu-239 and the rest of U-235 are calculated for one and three nuclear fuel cycles. Total amount of radioactive products of nuclear fission are also calculated. Total radioactivity of spent fuel value is estimated.

MOX-FUEL USING AT THERMAL NEUTRON REACTORS

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We have proved that MOX-fuel with 5% U-235 enrichment and 5% Pu-239 of uranium can be used in thermal neutron reactors 3 or 4 years fuel campaign with no significant reduction of β_{eff}. Initial concentration of Pu-239 can be increased up to 8% with respect to U-235 with no significant reduction of β_{eff}. In this case fuel campaign should not be longer than 3 years. MOX-fuel is one of the ways of excessive plutonium utilization.

PLASMA RECYCLING COMPLEX OF SOLID RW AT PILOT DEMONSTRATION ENGINEERING CENTER FOR DECOMMISSIONING (A BRANCH OF ROSENERGOATOM CONCERN JSC)

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Plasma radioactive waste reprocessing facility is located at the site of Novovoronezh NPP and intended for plasma pyrolysis of solid radioactive waste of medium and low radioactivity levels of complex morphological composition (containing both combustible and non-combustible components) produced during operation and decommissioning of power units at Novovoronezh NPP.

The applied method provides high rates of waste volume reduction (volume reduction factor 15 ~ 40), reducing the volume of secondary waste generated and obtaining the final product of reprocessing in the form of a fused slag compound with high mechanical strength and chemical stability with a concentration of at least 90% of the initial radionuclides in it.

The basis of Plasma radioactive waste reprocessing facility is a pit-type furnace consisting of a pit and a melter, units for waste loading and slag melt discharge. There are 2 arc plasmatrons installed in the upper part of the melter, these plasmatrons are direct current of "Radon-6" type with electric power from 50 to 150 kW (it is possible to use EDP-200). The identical plasmatron is additionally installed in the pyrolysis chamber.

The installed capacity of general and special purpose equipment is 1000 kW.

The capacity of Plasma radioactive waste reprocessing facility is from 5000 m³ per year under conditions of availability of data on produced morphological composition of the accumulated solid radioactive waste.

The routine operation mode in the pit furnace is implemented so that most of the radionuclides, emitted from the melter and removed with the discharge pyrolyses gases, is caught by adsorption in the pyrolyse porous mass in the middle part of the pit or through physical emission or condensation on the surface of the waste, after which it is re-directed to the area of the melting.

Under conditions of maintaining a constant level of waste in the furnace pit the selected operation modes provide the temperature gradient from 1300–1400 C in the hearth. The temperature of the pyrogas outlet is maintained at the level plus 250–300°C, which prevents the escape from the furnace of volatile compounds of a number of radionuclides and heavy metals.

Maintaining the temperature of the pyrogas in the upper part of the mine at the level of up to 300°C, the process ensures its explosion-protection.

As an additional measure intended to hold the temperature within the necessary limits, there envisaged an opportunity for irrigation of the upper part of the pit with water.

The automated mode of operation of the facility is the basic operation mode, in which the facility operates continuously 24 hours a day, at the same time, the hardware and software set performs all functions of the self-control, control and management of the process equipment, as well as applications and functions of the automated workstation.

The implementation of the solid radioactive waste plasma reprocessing at a nuclear power plant is a technologically and economically advantageous alternative to creation of multi-stage solid radioactive waste reprocessing facility on the basis of the processes of incineration, melting, cementing, pressing and super-compacting of the wastes, as well as eliminates the necessity for re-conditioning of the products of plasma waste reprocessing in 30–50 years.

Plasma radioactive waste reprocessing facility was put into commercial operation on 05.07.2017.

The license of Rostekhnadzor for operation of Plasma radioactive waste reprocessing facility was received on 07.07.2017.

1303 m^3 of solid radioactive waste was reprocessed in 2017.

RESTORATION OF PROPERTIES OF CIRCULATION PUMPS BLADES METAL OF NOVOVORONEZH NPP-2 UNIT No. 1 BY SURFACE ULTRASONIC IMPACT TREATMENT

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During transition period to market economy factories-manufacturers of equipment for nuclear industry became lame duck companies. Market of heavy industry equipment reduced dramatically, quality control requirements imposed to goods became lower. Deviations from regulations requirements, technical specifications for equipment manufacture result in inevitable decrease of reliability not only during operation stage but also during check tests. It is not always possible to promptly replace non-conforming equipment, in such cases it is required to apply compensatory measures to restore properties up to acceptable level in order to ensure operational reliability due to strength improvement of equipment parts and structures during the whole service life or up to the scheduled date of equipment replacement.

This paper is dedicated to development and practical implementation of surface ultrasonic treatment restoration technology used for working wheels blades metal of circulation pumps 16DPA10-28 located at Novovoronezh NPP-2 unit pump station 10URS. Dynamic surface treatment was implemented to compensate for process flaws of blades metal. It was demonstrated that impact elastic-plastic deformation has comprehensive compensation impact on blades metal of equipment initial state and creates surface hardening layer of 1.5 mm with higher strength properties. Surface strain hardening increases cyclic strength re-distributes beneficially residual process and maintenance stress as well as heals minor surface cracks improving surface quality. The developed technology was used for treatment of 32 blades of circulation pumps 10PAC01AP001, 10PAC02AP001, 10PAC03AP001, 10PAC04AP001 working wheels. 100-hours tests in situ proved high efficiency of developed technology and allow to recommend its application at the stage of blades manufacture as well as during pumps operation with the view to extend service life.

“ONE CONTROL ROD EJECTION” ACCIDENT ANALYSIS FOR THE NPP-2006 PROJECT USING DYN3D/SERPENT CODES

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The accident “One control rod ejection” from the reactor core of the NPP-2006 project (Belarusian NPP project) at the BOC, hot full power (HFP) was analyzed in the full-core model with reflector using DYN3D reactor code [1].

The necessary conservatism is achieved by selecting the appropriate initial and boundary conditions that ensure the most severe course of the considered accident process, taking into account a single failure (stuck highest worth control rod).

The results of the accident analysis for the HFP reactor state, which conservatively covers the states at the beginning and end of the stationary fuel loading, are presented in Table 1.

Table. 1. Chronology of events for the accident “One control rod ejection” at hot full power

Event	Time, s	Calculated value	Limiting value
Start of the one control rod ejection	0.0	–	–
Signal to actuate the reactor trip system due to neutron power exceeding (signal is skipped), $N > 108\% N_{nom}$	0.027	–	–
End of the one control rod ejection	0.1	–	–
Maximum reactivity value	0.1	0.47 $	–
Maximum neutron power value	0.12	6382 MW	–
Signal to actuate the reactor trip system due to reduction of DNBR (DNBR<1.35)	0.38	–	–
Beginning of the heat exchange crisis	0.38	DNBR<1	–
Maximum thermal power value	1.17	3963 MW	–
Beginning of the all control rod movement	3.38	–	–
Maximum enthalpy value	3.65	580.5 kJ/kg	830 kJ/kg
Maximum fuel temperature	3.8	2506 °C	2540 °C
Maximum fuel cladding temperature	4.05	927 °C	1200 °C
End of heat exchange crisis	5.2	DNBR>1	–
End of the all control rod movement	7.38	–	–
End of calculation	30.0	–	–

The results of the calculations show that all acceptance criteria for the accident “One control rod ejection” at the HFP are met.

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ANEUTRONIC NUCLEAR REACTIONS IN THE LASER PRODUCED PLASMA – NEW RESULTS, NEW PERSPECTIVES

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The results of work on the world laser installations on the study of the neutron-free nuclear fusion reaction $p + {}^{11}B$ are presented. The possibilities and prospects for the development of this type of nuclear synthesis for the creation of new nuclear power systems are shown.

The results of studies of the reaction $p + {}^{11}B$ at the «Neodym» installation at laser intensity of $5 \cdot 10^{18}$ W/cm^2 are presented. At the «Neodym» laser installation, the nuclear reaction $p + {}^{11}B \rightarrow 3\alpha$ with a yield of $\sim 10^3$ alpha particles was realized for the first time in the world [1]. At the present time, an output of alpha particles of $\sim 10^8$ per pulse has been obtained at the modernized «Neodym» facility. The investigations were carried out for different targets and geometry of the experiment.

It is shown that the reaction $p + {}^{11}B$ can have a chain avalanche character [2]. This is due to the fact that α-particles formed during the interaction reaction with ${}^{11}B$ nuclei lead to the generation of protons with resonance energy for the primary $p + {}^{11}B$ reaction.

Taking into account secondary reactions, nuclear reactions based on the $p + {}^{11}B$ reaction form a closed chain boron-hydrogen complementary cycle. This opens up new prospects for aneutronic nuclear fusion based on the reaction $p + {}^{11}B$.

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RADIATION-CHEMICAL TRANSFORMATIONS IN AQUEOUS SOLUTIONS OF FORMIC, OXALIC AND NITRIC ACID MIXTURES AS MODEL SYSTEMS OF RADIOACTIVE LIQUID WASTES

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Oxalic, formic and nitric acids are the main components of the liquid radioactive wastes (LRW), formed during the utilization of nuclear materials used in radiochemical technologies.

The dose dependences of the formation of gaseous products (H_2,CO_2), the formation of H_2O_2, as well as the pH change, Chemical Oxygen Demand (COD), and UV- spectra of irradiated samples at various doses (2–80 kGy) were studied. The radiolysis of aqueous solutions of mixtures of formic, oxalic and nitric acids at different concentrations was studied. The solutions were irradiated by γ-irradiation by of ^{60}Co isotope under static conditions, in glass ampoules at room temperature. The dose rate was determined by ferrosulfate dosimetry and was 0.16 Gy/s.

Fig. 1 shows the kinetics of COD change on depending from adsorbed dose of aqueous solutions of mixtures of formic-oxalic and formic-oxalic-nitric acids, at its different initial concentrations.

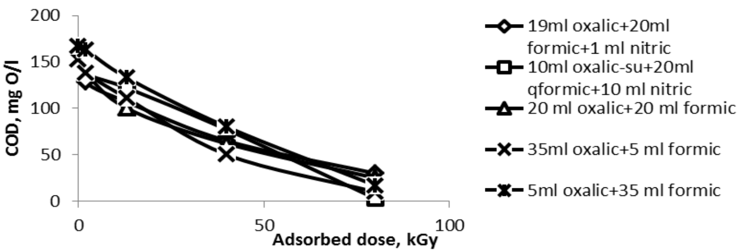

Fig.1. Kinetics of the COD change on depending from adsorbed dose of mixtures of aqueous solutions of formic-oxalic and formic-oxalic-nitric acids (D = 2–80 kGy, P = 0.16 Gy/s).

As seen from Fig. 1, with increasing absorbed dose, the transformation of organic fraction is decreases. The strongest change of COD (~98%) occurs in the 10 ml-oxalic-20 ml formic-10 ml nitric acid system. On the basis of the obtained experimental data, the mechanism of chemical conversion and possible risks of radiation and chemical safety in the storage of liquid radioactive wastes are discussed.

INVESTIGATION OF THE DESTRUCTION PROCESSES OF FUEL-CONTAINING MATERIALS WITH MICROBIOTA

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As previous studies have shown a number of soil fungi species and bacteria retain an activity high level in the nuclear waste storages containing. Also it was discovered they can change the solubility and bioavailability of transuranic nuclides such as plutonium.

For study the effect of irradiated generations of micromycetes various strains on the destruction of different fuel-containing materials in model systems, it were carried out experiments for 2 strains of irradiated generations of Cladosporium cladosporioides with positive radioadaptive properties and two fragments of Chernobyl origin irradiated nuclear fuel, which had a significant activity of ^{241}Am. Studies of mycelium and culture liquid were carried out using a semiconductor Ge-spectrometer with an energy resolution of 1.5 keV in the gamma-line 661 keV ^{137}Cs. After analyzing the obtained results, it was first discovered that the C. cladosporioides strains convert ^{241}Am from solid particles into bioavailable forms. The assimilation of ^{241}Am isotopes by micromycetes strains dominates in comparison with their conversion into a soluble form. The ^{241}Am activity in the mycelium was 10 times higher than it activity in the culture liquid. At the same time control experiment were carried out. The only culture liquid and fuel particles were used in model system. The presence of ^{241}Am activity in the culture liquid without strains was not detected during control experiment.

The same experiment was also conducted with the strain of the C.cladosporium irradiated generation with positive radioadaptive properties and the fuel particle containing Pu and ^{241}Am isotopes. Radiochemical and alpha-spectrometric studies of the mycelium and culture liquid were carried out after the experiment. The activity of ^{239,240}Pu and ^{238}Pu + ^{241}Am was found in the mycelium. Thus, we first observed the assimilation with C. cladosporium strains of plutonium isotopes. And the rate of these isotopes assimilation was similar to the rate of ^{241}Am assimilation.

DEVELOPING THE DESIGN METHODS FOR HEAT GENERATION IN HIGH LEVEL WASTE OF NPP

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High-level waste from nuclear power plants is stored in packages (containers) in special storage facilities. However, since radioactive decay is accompanied by the release of significant energy, there are limitations on heat generation within the package and, in general, in the storage. According to the requirements of federal laws, for radioactive waste of grades 1 and 2, a standardized index for the heat release of the radioactive contents of the package is introduced. In this paper, we propose a calculation method for estimating the heat release based on the radiation characteristics of the radionuclides specified in the packaging certificate and determined using existing methods. To calculate the heat release, it is necessary to determine the kinetic energy of the decay products lost inside the container. In this case, the energy that is carried outside the container is determined in large part by the energy of the neutrino (antineutrinos) and the energy of gamma quanta, which can penetrate beyond the container, but will be absorbed into the storage. It is possible to calculate the heat release power using the activity of the corresponding radioactive elements. The alpha energies, the gamma of decays, the average energy of the electrons in the beta spectrum, and the outputs per channel are known with high accuracy. As a result, the accuracy of calculating the heat release is determined by the accuracy of the initial data on the composition and activities of radioactive waste.

Specific heat release can be calculated by the formula: $Q = \sum_{I=1}^{N} A_i \cdot \varepsilon_i$, where N is the number of radionuclides contributing to heat release, A_i is the activity of the *i*-th nuclide, ε_i is the average energy of all types of radioactive decay (alpha, beta, gamma and internal conversion) for a given radionuclide. The average energy of all types of radioactive decay for an individual nuclide is calculated by the formula: $\varepsilon_i = \varepsilon_i^{\alpha} + \varepsilon_i^{\beta} + \varepsilon_i^{\gamma}$, where ε_i^{α}, ε_i^{β}, ε_i^{γ} – average energies of alpha, beta, and gamma decays, respectively, including decays of daughter nuclides.

With the known activities of A_i nuclides, the specific heat release power Q is equal to $Q = (\sum_{I=1}^{N} A_i \cdot \varepsilon_i) \cdot ktr$, where ε_i is the total average energy attributable to one decay of the *i*-th isotope, $ktr = 1.602 \cdot 10^{-13}$ is the energy conversion factor expressed in MeV to Joule. The total mean energies for the nuclides characteristic of NPP have been calculated with an accuracy of at least 5%.

RETRAINING OF EXPERTS FOR RADIATION THERAPY IN LOMONOSOV MOSCOW STATE UNIVERSITY

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Now in our country release very small number of experts who work in radiation technologies in various spheres of national economy (in the industry, agriculture and medicine).

Trained experts are necessary for functioning and effective operation of hi-tech diagnostic and therapeutic complexes. First, it is about medical physicists who are responsible for providing requirements of accuracy when leading of the required dose of ionizing radiation to a tumor with the minimum defeat of the next healthy body tissues, for a quality assurance and safety of beam treatment. And, about engineers on operation of the accelerators working in medical institutions. Accurate interaction of the doctor and the medical physicist with support of the engineer on operation of the accelerating equipment is necessary for effective work on beam treatment of patients.

The additional professional educational program for professional retraining specialists in the branch of radiotherapy for the development, operation and application of high-tech systems in clinical institutions is described in the report. The program is developed at the Department of Physics of Accelerators and Radiation Medicine of the Physical Department of Lomonosov Moscow State University. The RUSNANO Foundation for Educational Programs participated in financing of the program. Training is conducted for specialists with master diplomas or the diplomas of high education. The development of a system for assessment of practicing medical physicists, engineers and dosimetrists also is discussed in the report.

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METHOD OF THE TOTAL NEUTRON CROSS SECTION MEASUREMENT BY SEMICONDUCTOR Si DETECTOR

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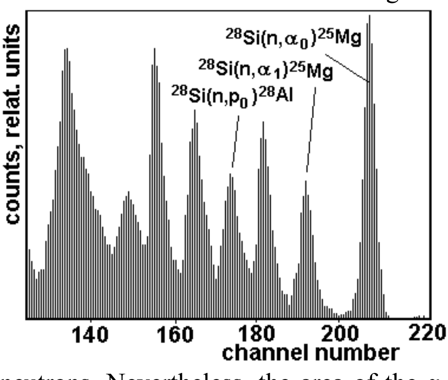
The neutron total cross section is a basic quantity describing the interactions of neutrons with nuclei. Commonly the activation or time-of-flight methods are used which are rather complicated. A simple method is proposed which is based on the interaction of fast neutron with ^{28}Si nuclei in material of detector, specifically, the reaction $^{28}Si(n,\alpha_0)^{25}Mg$ with forming ^{25}Mg in the ground state. The high energy part of spectrum of the reaction products which is obtained at irradiation of the semiconductor Si detector by neutron flux (E_n= 14.1 MeV) is presented in Figure. The high energy α_0 group of α-particles is well separated from other groups. Its (and others) area is proportional to the integrated flux of the primary neutrons passed through a detector.

In our test experiment the energy spectrum of the reaction products detected by Si detector was measured at placing the target of natural lead between the neutron source and detector. The irradiation was carried out by the same integral of the neutron flux as without a target. The target has a cylindrical form with diameter 16 mm and length 80 mm, and located both from the neutron source and detector at distances 100. The diameter of entrance window of the detector is equal to 12 mm and the thickness of its sensitive volume is 1.5 mm. The resulting spectrum was reduced in comparison with that obtained without a target, and the peaks are slightly smoothed because of appearance the inelastic scattered neutrons. Nevertheless, the area of the α_0 group, corresponding to the primary neutron energy, can be easy marked out. It should be mentioned that for the needed good quality of the energy spectrum the thickness of the used detector should be more than a range of the high energy α_0 particles, and its own energy resolution should be well (~1%).



The total neutron cross section was evaluated by standard neutron transmission method through the ratio of areas of the peaks corresponding to the reaction $^{28}Si(n,\alpha_0)^{25}Mg$, and its value of ~5.2 barn was obtained, which is well agreed with the literature value σ_{tot}= 5.34 barn [1] at the energy 14.7 MeV.

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INFLUENCE OF POWERFUL RADIATION ON A THERMONUCLEAR TARGET THERMAL DEFORMATION

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Developing of high energy density systems requires the theoretical and experimental study of underlying process, such as the irradiation of fusion targets with a system of powerful laser pulses in the presence of a strong magnetic field and its subsequent compression to the conditions in which a thermonuclear reaction can be arisen [1–4]. The use of an intense magnetic field simplifies the conditions for the ignition of a thermonuclear reaction in the target. At the initial stage of compression, significant thermal gradients occur in the target because of powerful radiation. This gradients can lead to a change in its geometry due to thermal deformations and, therefore, to prevent its uniform compression [5–8].

This paper is devoted to the evaluation of thermal deformations arising in the fusion targets under the influence of powerful laser radiation and the strong magnetic field presence. A two-layer cylindrical target (length $1.5{\cdot}10^{-3}$ m, diameter $4.3{\cdot}10^{-4}$ m, $2{\cdot}10^{-5}$ m plastic shell) is considered. The laser radiation flux (magnitude is $10^{12} - 10^{18}$ W/cm^2, the spot diameter is 10^{-5} m) are specified on the target surface, and the effect of the magnetic field (initial field magnitude is 0.1 T) is taken into account. Temperature distributions were obtained and thermal deformations of this target were estimated.

The work is supported by the Ministry of Education and Science of the Russian Federation (Project № 13.5240.2017 / 8.9).

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TREATMENT OF LIQUID RADIOACTIVE WASTE GENERATED DURING THE DECOMMISSIONING OF SMALL RESEARCH FACILITIES

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The results of liquid radioactive waste treatment generated during of operation and decommissioning of spent fuel storage are presented. The decommissioning process of this object led to the formation of significant volumes of LRW contaminated with actinides Pu and Am. Treatment of decontamination solutions is a challenging issue due to the complicated radiochemical composition of such LRW. It is characterized by rather high salinity (from 0.7 up to 2 g/l), organic ligands and surfactants (permanganate oxidation from 9 up to 32 mg O_2/dm^3), solution pH ranged 8–9. LRW categories are low- and intermediate levels. The specific activity of the fresh solutions was (10^2–10^6) Bq/l. After ageing for a few years the specific activity of the solutions was decreased up to (10^1–10^4) Bq/l.

The process of the appropriate treatment method selection should be based on the determination of radionuclide species in solution. The selection of the most effective combination of methods for LRW treatment based on the data on the state of radionuclides. The methods of ion exchange, sorption, coagulation, oxidation and membrane separation were used.

The speciation of Pu and Am radionuclides in fresh and aged decontamination solutions were obtained. It was shown that the aging of solutions causes the sedimentation of radionuclides and organic components up to 90% on the bottom of the vessel and the state of radionuclides changes with aging from predominantly colloidal species to soluble complexes with organic reagents. Soluble forms of Pu and Am passing through a membrane of 1 nm are presumably their mononuclear complexes with 1-hydroxyethane-1,1-diphosphonic acid.

In consideration of the speciation of Pu and Am the effective technology based on combination of permanganate oxidation, coagulation and membrane methods for LRW treatment was developed. The feature of this method is that the products of manganese reduction form good collectors for Pu and Am radionuclides. There were received decontamination factors ~100 and ~25 for low and high salinity solutions respectively.

Thus it was established Pu and Am speciation in decontamination solution aged for few years: Pu forms predominantly pseudo-colloids whereas Am is distributed between pseudo-colloids and mononuclear complexes with organic ligands. Oxidation of the solution components leads to the formation of pseudo-colloid species. To achieve the efficiency of selected methods for aged decontamination LRW treatment pre-oxidation by O_3 or $KMnO_4$ is the proposed step of the LRW treatment.

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